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Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992

Volume 1: Third Comparison with 40 CFR 191, Subpart B

WIPP Performance Assessment Department

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
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WIPP Performance Assessment Department
Sandia National Laboratories
Albuquerque, New Mexico 87185

ABSTRACT

Before disposing of transuranic radioactive wastes in the Waste Isolation Pilot Plant (WIPP), the United States Department of Energy (DOE) must evaluate compliance with applicable long-term regulations of the United States Environmental Protection Agency (EPA). Sandia National Laboratories is conducting iterative performance assessments of the WIPP for the DOE to provide interim guidance while preparing for final compliance evaluations.

This volume contains an overview of WIPP performance assessment and a preliminary comparison with the long-term requirements of the *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR 191, Subpart B)*. Detailed information about the technical basis for the preliminary comparison is contained in Volume 2. The reference data base and values for input parameters used in the modeling system are contained in Volume 3. Uncertainty and sensitivity analyses related to 40 CFR 191B are contained in Volume 4. Volume 5 contains uncertainty and sensitivity analyses of gas and brine migration for undisturbed performance. Finally, guidance derived from the entire 1992 performance assessment is presented in Volume 6.

Results of the 1992 performance assessment are preliminary, and are not suitable for final comparison with 40 CFR 191, Subpart B. Portions of the modeling system and the data base remain incomplete, and the level of confidence in the performance estimates is not sufficient for a defensible compliance evaluation. Results are, however, suitable for providing guidance to the WIPP Project.

All results are conditional on the models and data used, and are presented for preliminary comparison to the Containment Requirements of 40 CFR 191, Subpart B as mean complementary cumulative distribution functions (CCDFs) displaying estimated probabilistic releases of radionuclides to the accessible environment. Results compare three conceptual models for radionuclide transport in the Culebra Dolomite Member of the Rustler Formation and two approaches to estimating the probability of inadvertent human intrusion into the WIPP by exploratory drilling. The representation for disposal-system performance believed to be most realistic includes intrusion probabilities based on expert-panel judgment and dual-porosity transport with chemical retardation. For intrusions occurring 1000 years after decommissioning, the mean CCDF for this representation lies more than one order of magnitude below the EPA limits. Using the same approach to intrusion probabilities used in the 1991 performance assessment (i.e., not taking expert judgment into account and basing the probability model on the maximum intrusion probability indicated in Appendix B of 40 CFR 191, Subpart B) significantly increases the probability of releases, regardless of the model used for subsurface transport. Assuming the higher intrusion probabilities and dual-porosity transport without chemical retardation, the mean CCDF is approximately one order of magnitude below the EPA limits. For the higher intrusion probabilities and single-porosity, fracture-only transport, the mean CCDF is less than one order of magnitude below the EPA limits.

This volume of the report should be referenced as:

WIPP PA (Performance Assessment) Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992—Volume 1: Third Comparison with 40 CFR 191, Subpart B*. SAND92-0700/1. Albuquerque, NM: Sandia National Laboratories.

ACKNOWLEDGMENTS

The Waste Isolation Pilot Plant (WIPP) Performance Assessment (PA) Department is comprised of both Sandia National Laboratories (SNL) and contractor employees working as a team to produce preliminary comparisons with Environmental Protection Agency (EPA) regulations, assessments of overall long-term safety of the repository, and interim technical guidance to the program. The on-site team, affiliations, and contributions to the 1992 performance assessment are listed in alphabetical order:

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The foundation of the annual WIPP performance assessment is the underlying data set and understanding of the important processes in the engineered and natural barrier systems. Other SNL Departments are the primary source of these data and understanding. Assistance with the waste inventory comes from Westinghouse Electric Corporation and its contractors. We gratefully acknowledge the support of our departmental and project colleagues. Some individuals have worked closely with the performance assessment team, and we wish to acknowledge their contributions individually:

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PREFACE

The ***Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992*** is currently planned to consist of six volumes. The titles of the volumes are listed below. This report is the third in a series of annual reports that document ongoing assessments of the predicted long-term performance of the Waste Isolation Pilot Plant (WIPP); this documentation will continue during the WIPP Test Phase. However, the Test Phase schedule and projected budget may change; if so, the content of the ***1992 Preliminary Performance Assessment*** report and its production schedule may also change.

Volume 1: Third Comparison with 40 CFR 191, Subpart B

Volume 2: Technical Basis

Volume 3: Model Parameters

Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B

Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance

Volume 6: Guidance to the WIPP Project from the December 1992 Performance Assessment

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1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is a research and development project of the United States Department of Energy (DOE). The WIPP is authorized by Congress (Public Law 96-164, 1979) and is designed as a full-scale, mined geologic repository to demonstrate the safe management, storage, and disposal of transuranic (TRU) radioactive wastes generated by DOE defense programs since 1970. In addition to TRU radionuclides, the wastes may contain hazardous (nonradioactive) constituents. Before permanently disposing of radioactive wastes in the WIPP, the DOE must evaluate the repository based on various regulatory criteria for disposal of all the waste components, and the United States Environmental Protection Agency (EPA) must certify that compliance has been satisfactorily demonstrated.

Performance assessments will form the basis for evaluations of compliance with applicable long-term regulations of the EPA, including regulations pertaining to both radioactive and hazardous wastes (see Section 1.2 for a discussion of applicable regulations). This volume provides an overview of WIPP performance assessment and summarizes the December 1992 preliminary comparison with 40 CFR Part 191, Subpart B, which contains the long-term requirements of the *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (US EPA, 1985). Results presented here are preliminary and are not suitable for final comparison with 40 CFR 191, Subpart B. Portions of the modeling system remain incomplete, and the level of confidence in the performance estimates is not sufficient for a defensible compliance evaluation. Results are suitable for providing interim guidance to the WIPP Project as it prepares for a final compliance evaluation.

Several DOE documents explain the relationship between long-term regulatory information needs and the experimental programs that will fill those needs. The ***WIPP Test Phase Plan*** (US DOE, 1990a, currently in revision) contains descriptions of experimental programs related to disposal room and drift systems (see also Section 2.4 of this volume and Volumes 2 and 3 of this report), TRU-waste experiments, sealing systems and rock mechanics, hydrology of and transport within the host rock for the WIPP, and flow and transport in rock layers surrounding the WIPP. For each experimental program, the document describes the relevant information needs identified by performance assessments (defined in Section 3.3.1 of this volume) and indicates how the program has been designed to fill those needs.

The technical needs for laboratory and field experiments involving TRU and TRU-mixed waste and simulated waste have been assessed (US DOE, 1992a). These tests are designed to provide information on two topics identified as important for evaluating regulatory compliance: generation of gas from degradation of TRU wastes (defined in Section 2.5.1 of this volume), and the concentration of radionuclides and hazardous constituents within disposal-room brine, both as dissolved species and as colloids.

Extensive laboratory and field studies conducted during the Site Characterization Phase for the WIPP have provided information used to date in performance assessments of the WIPP. References for these studies and discussion of how their results are used in performance assessments are provided in *WIPP Test Phase Activities in Support of Critical Performance Assessment (40 CFR 191 B) Information Needs* (US DOE, 1992b), which is a document prepared by the DOE for the National Academy of Sciences (NAS) WIPP Panel (referred to in Section 1.1.1 of this volume), and in other reports (Tyler et al., 1988; Lappin et al., 1989; US DOE, 1990a).

This report documents the third in a series of preliminary analyses of predicted long-term performance of the WIPP that Sandia National Laboratories (SNL) conducts for the DOE. Preparation for preliminary performance assessments began with the December 1989 *Draft Forecast of the Final Report for the Comparison to 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant* (Bertram-Howery et al., 1989) and *Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant* (Marietta et al., 1989). The 1990 report (Bertram-Howery et al., 1990) and two supporting volumes (Rechard et al., 1990a; Helton et al., 1991) presented preliminary results of evaluations that addressed only the long-term performance criteria for disposal specified in the radioactive-waste disposal standards (40 CFR 191, Subpart B, US EPA, 1985; see Chapter 3 and Appendix A of this volume). The 1991 version of the report (WIPP PA Division, 1991a,b,c; Helton et al., 1992) presented preliminary evaluations for comparison with the regulatory requirements of 40 CFR 191, Subpart B. A preliminary safety assessment that evaluates possible long-term consequences to the public health as a result of radioactive wastes emplaced in the WIPP is currently being prepared.

This 1992 report updates the preliminary results of the analyses included in the 1991 version of the report. Where data and models are available, the report presents preliminary results that preview a final report. With respect to the disposal of radioactive wastes, this 1992 report is a valid preview only to the extent that 40 CFR 191, Subpart B, which was promulgated by the EPA in 1985 and remanded by a U.S. Appeals Court in 1987 (NRDC v. US EPA, 1987), is the same as the vacated 1985 version. This report treats the vacated portion of 40 CFR 191 as if it were still effective because the DOE and the State of New Mexico have agreed that compliance planning will continue on that basis until a new Subpart B is promulgated (US DOE and State of New Mexico, 1981, as modified). The *Waste Isolation Pilot Plant Land-Withdrawal Act* (Public Law 102-579, 1992), which mandates specific actions before the Test Phase for the WIPP can begin (see Section 1.1 of this volume), reinstates those portions of 40 CFR 191, Subpart B, that were not the subject of the 1987 remand and requires the EPA to repromulgate the regulation by April 30, 1993. The major quantitative requirement of the regulation addressed in this volume of the report is among those reinstated, and the methodology reported here has not been modified to reflect the EPA's efforts to develop a new Subpart B.

1.1 Description of the WIPP Project

The WIPP is located in semiarid rangeland in southeastern New Mexico. The nearest major population center is Carlsbad (population 25,000 in the 1990 U.S. census), 42 km (26 mi) west of the WIPP (Figure 1-1). Two smaller communities, Loving (population 1,500) and Malaga (population 150), are about 33 km (20 mi) to the southwest. Population density closer to the WIPP is very low; fewer than 30 permanent residents live within a 16-km (10-mi) radius. The nearest residents live 5.6 km (3.5 mi) south of the WIPP surface facility (US DOE, 1990b).

The surface of the land at the WIPP has been leased for cattle grazing. None of the ranches within 10 miles use well water for human consumption because the water contains large concentrations of total dissolved solids. Potash, oil, and gas are the only known important mineral resources. The surrounding area is used primarily for grazing, potash mining, and hydrocarbon exploration and production (US DOE, 1990b).

The WIPP repository is in bedded salt about 655 m (2,150 ft) below the land surface. The location was chosen because features of the regional and local geologic and hydrologic environment are expected to provide excellent natural barriers to radionuclide migration (see Chapter 2 of this volume and Volume 2 of this report).

The *Waste Isolation Pilot Plant Land Withdrawal Act* (Public Law 102-579, 1992) transferred ownership of 16 square miles (41 km^2) at the WIPP (Figure 1-2) from the U.S. Bureau of Land Management to the DOE. The boundary indicated as "WIPP" on illustrations in this volume is the

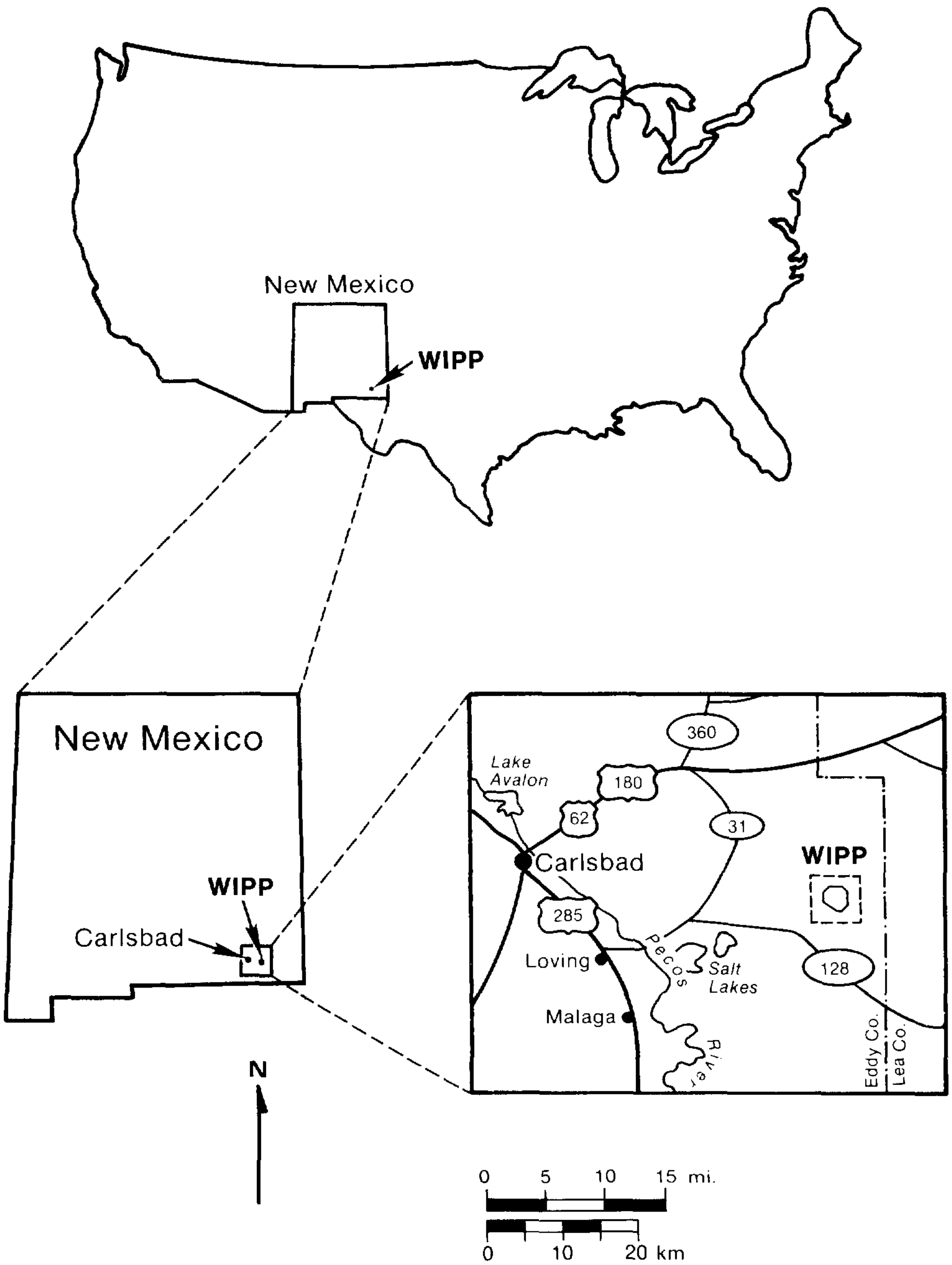

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Figure 1-1. WIPP location map (after Bertram-Howery and Hunter, 1989a).

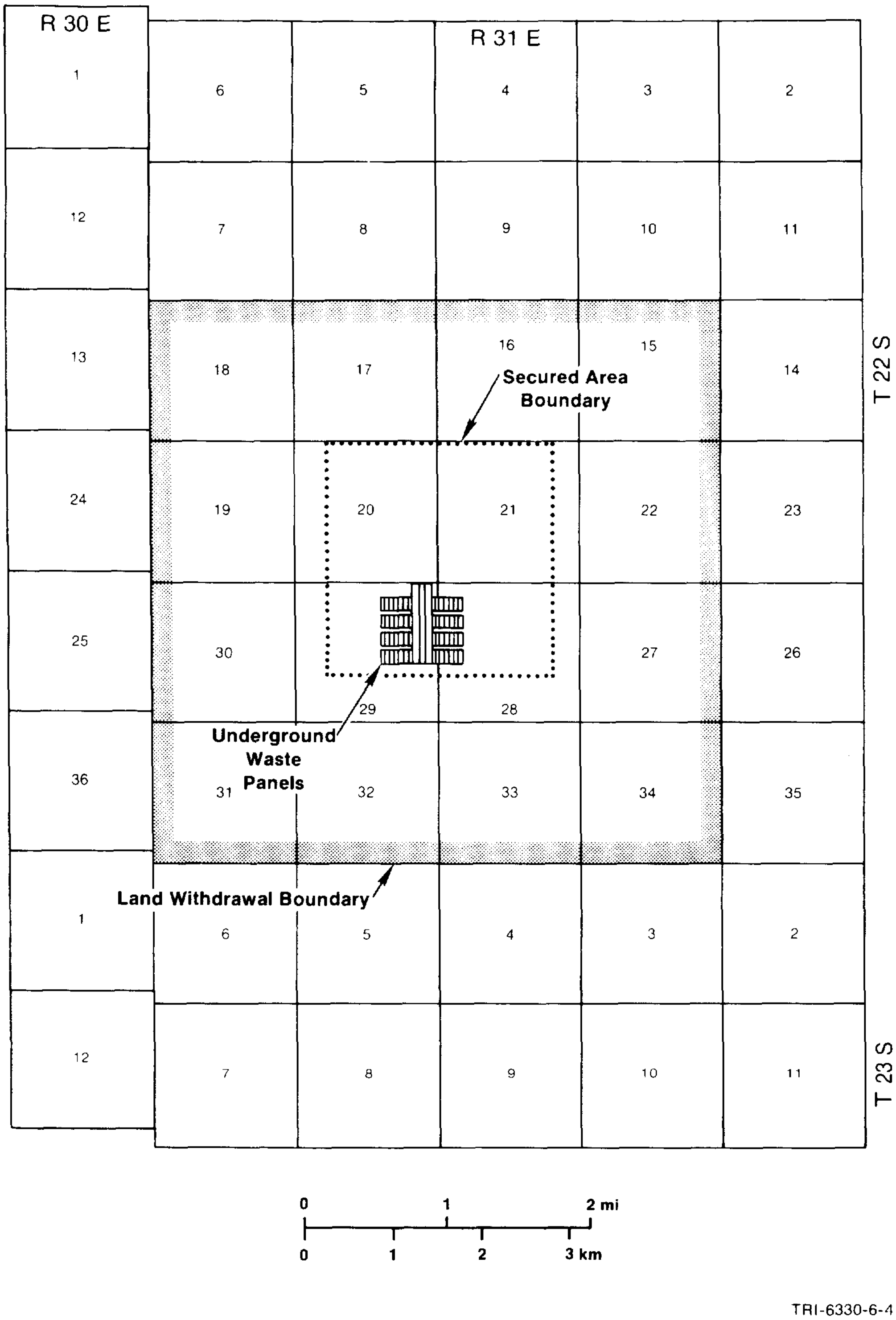

Figure 1-2. Position of the WIPP waste panels relative to WIPP boundaries and surveyed section lines (US DOE, 1989).

boundary of the land-withdrawal area. The legislation also outlined requirements for the Test and Disposal Phases of the WIPP.

The WIPP Test Phase is scheduled to begin when the following criteria, stated in the *WIPP Land Withdrawal Act* (Public Law 102-579, 1992, Section 6), are met: the final 40 CFR 191 regulation is issued and published in the *Federal Register*; the EPA has determined that the DOE has complied with the terms and conditions of the No-Migration Determination for the *Resource Conservation and Recovery Act* (RCRA) (see Section 1.2 of this volume); the EPA has approved the WIPP Test Phase plan and the waste-retrieval plan for the Test Phase; the U.S. Department of Labor has approved training programs for emergency response; the DOE has issued a plan to ensure the safety of Test Phase activities, including using mined rooms that are supported to assure safety during testing, and the Secretary of Labor has reviewed and concurred with the plan; and the DOE has agreed to provide to the EPA biennial performance-assessment reports during the Test Phase that document the analyses of long-term performance of the WIPP. Only EPA-approved transuranic waste in quantities no greater than 1/2 of 1 percent of the total capacity of the WIPP may be emplaced during the Test Phase. Remote-handled (RH) TRU waste (defined in Section 2.5.1 of this volume) may not be emplaced during the Test Phase.

As stated in the *WIPP Land Withdrawal Act* (Public Law 102-579, 1992, Section 7), the DOE may begin disposing of TRU waste in the WIPP when: the EPA has certified that the WIPP facility will comply with 40 CFR 191; the DOE has submitted to Congress plans for decommissioning the WIPP and post-decommissioning management; 180 days have elapsed after notice to Congress that the WIPP has met the provisions of 40 CFR 191, the *Clean Air Act*, the *Solid Waste Disposal Act*, the *Safe Drinking Water Act*, the *Toxic Substances Control Act*, the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, and all other applicable Federal laws pertaining to public health and safety or the environment (including the *Resource Conservation and Recovery Act*, see Section 1.2.2); the DOE has acquired oil and gas leases specified by the EPA; the DOE has submitted to Congress comprehensive recommendations and a timetable for disposal of all DOE-controlled transuranic waste; and the DOE has completed a survey that identifies all TRU-waste types at all sites from which wastes are to be shipped to the WIPP.

1.1.1 Participants

The DOE implements the WIPP Project through the WIPP Project Integration Office (Albuquerque, NM), the WIPP Project Site Office (Carlsbad, NM), and its Headquarters in Washington, DC. The WIPP Project Offices are assisted by two prime contractors: Waste Isolation Division (WID) of Westinghouse Electric Corporation (WEC) and Sandia National Laboratories (SNL). WID is responsible for all facility operations and for compliance with management and storage regulations. SNL, as the scientific program manager, is responsible for developing an understanding of the processes and systems that affect long-term isolation of wastes in the WIPP. That understanding is applied by SNL to the evaluation of the long-term performance of the repository. SNL defines and implements, subsequent to DOE approval, experiments both in laboratories and at the WIPP. In addition, SNL develops and applies models both to interpret experimental data and to assess the performance of the repository.

Federal agencies that provide oversight during the Test and Disposal Phases of the WIPP Project are the U.S. Mine Safety and Health Administration; the U.S. Bureau of Mines; the Occupational Safety and Health Administration; the National Institute for Occupational Safety and Health; and the U.S. Nuclear Regulatory Commission, which oversees transportation of waste to the WIPP.

The ***WIPP Land Withdrawal Act*** (Public Law 102-579, 1992) provides for review of the assessment of long-term repository performance:

> "The [DOE] shall publish, during the test phase, a biennial performance assessment report, consisting of a documented analysis of the long-term performance of WIPP. Each such report shall be provided to the State [of New Mexico], the [EPA], the National Academy of Sciences, and the EEG [Environmental Evaluation Group] for their review and comment.
>
> If, within 120 days of the publication of a performance assessment report under [the previous] paragraph, the State, the [EPA], the National Academy of Sciences, or the EEG provide written comments on the report, the [DOE] shall submit written responses to the comments to the State, the [EPA], the National Academy of Sciences, and the EEG, and to other appropriate entities or persons after consultation with the State, within 120 days of receipt of the comments" (Public Law 102-579, 1992, Section 6).

The DOE and the State of New Mexico have an Agreement for Consultation and Cooperation (US DOE and State of New Mexico, 1981, as modified). This agreement enables the State, through the Radioactive Waste Consultation Task Force and other agencies, to have an active part in assuring that public safety issues are addressed fully. The New Mexico Environment Department has authority concerning permitting in compliance with the RCRA (see Section 1.2).

The EPA's Office of Radiation and Indoor Air and Office of Solid Waste and Emergency Planning maintain a dialog with the WIPP Project concerning relevant issues. In addition, as explained in Section 1.1 of this volume, the *WIPP Land Withdrawal Act* gave the Administrator of the EPA specified responsibilities regarding approval of the Test and Disposal Phases for the WIPP.

Review of the scientific basis for the WIPP Project is provided by the National Research Council's (of the National Academy of Sciences) Board on Radioactive Waste Management's WIPP Panel.

The Environmental Evaluation Group (EEG) has provided oversight of the WIPP Project since before the WIPP's formal authorization in 1979. The EEG is responsible for independent technical evaluation of the WIPP with regard to the protection of public health and safety and the protection of the environment. Assignment of the EEG to the New Mexico Institute of Mining and Technology occurred with passage of the National Defense Authorization Act (Public Law 100-456, 1988).

Written comments from these reviewers, if provided, and responses about the annual performance assessment are published as Appendix B of this volume.

1.1.2 Wastes

The TRU wastes for which the WIPP is designed are defense-program wastes generated by United States government activities since 1970. The wastes consist of laboratory and production materials contaminated by certain TRU radionuclides and other radioactive and hazardous constituents. If approved, the following 10 DOE TRU-waste generator and/or storage sites are scheduled to ship TRU wastes to the WIPP: Idaho National Engineering Laboratory, Rocky Flats Plant, Hanford Reservation, Savannah River Site, Los Alamos National Laboratory, Oak Ridge National Laboratory, Nevada Test Site, Argonne National Laboratory-East, Lawrence Livermore National Laboratory, and Mound Laboratory (US DOE, 1990c). More information about the wastes scheduled for disposal in the WIPP are in Chapter 2 of this volume and Volume 3 of this report.

1.2 Regulatory Criteria for the WIPP

The EPA regulations applicable to the long-term performance of the WIPP include Subpart B of 40 CFR 191, promulgated in 1985 but remanded to the EPA in 1987 for reconsideration, and the regulations implementing the

Resource Conservation and Recovery Act (Public Law 94-580, 1976). The Council on Environmental Quality promulgated the regulations for implementing the *National Environmental Policy Act* (NEPA) (Public Law 91-190, 1970, as amended; US EPA, 1978); however, the EPA has the responsibility for reviewing and publicly commenting on potential environmental impacts of major federal actions. Additional requirements are specified in the *WIPP Land Withdrawal Act* (see Section 1.1 of this volume).

1.2.1 Radioactive-Waste Disposal Standards (40 CFR 191)

The radioactive-waste disposal standards, *40 CFR Part 191—Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (US EPA, 1985), are divided into two subparts. Subpart A applies to a disposal facility prior to decommissioning and limits annual radiation doses from waste management and storage operations to members of the public in the general environment. Subpart B applies after decommissioning and sets probabilistic limits on cumulative releases of radionuclides to the accessible environment (defined in Section 3.2.2 of this volume) for 10,000 years. Subpart B also sets probabilistic limits on both radiation doses to members of the public in the accessible environment for 1000 years of undisturbed performance (defined in Section 3.5 of this volume) and radioactive contamination of certain sources of groundwater within or near the controlled area (defined in Section 3.2.3 of this volume) for 1000 years after disposal. The DOE must provide a reasonable expectation that the WIPP will comply with the quantitative requirements of Subpart B of 40 CFR 191. Appendix A of 40 CFR 191 specifies how to determine release limits; Appendix B of 40 CFR 191 provides nonmandatory guidance for implementing Subpart B. The regulation is reproduced as Appendix A of this volume, and the specific requirements of 40 CFR 191, Subpart B, are discussed in Chapter 3 of this volume.

Volumes 1 through 4 of this report document the preliminary results of the evaluations of the long-term performance of the WIPP for the third comparison with the requirements of 40 CFR 191, Subpart B. The quantitative evaluation of the long-term performance of the WIPP with respect to Subpart B of 40 CFR 191 also forms the basis for safety assessments and for uncertainty and sensitivity analyses to identify parameters and processes that are important for evaluating transport of nonradioactive hazardous wastes regulated under 40 CFR 268 (see Section 1.2.2).

1.2.2 Resource Conservation and Recovery Act (RCRA)

The *Resource Conservation and Recovery Act* (RCRA) (Public Law 94-580, 1976) was enacted to provide management of hazardous wastes. The long-term regulations promulgated for implementing the RCRA, specifically 40 CFR 268 (US EPA, 1986) for the WIPP, prohibit land disposal of specified hazardous wastes, including volatile organic compounds and heavy metals, unless the owner or operator of the facility petitions for a variance and successfully demonstrates "to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit or injection zone for as long as the wastes remain hazardous" or the waste is treated in accordance with applicable treatment standards (40 CFR 268.6(a), US EPA, 1986). Guidance provided by the EPA on the interpretation of this wording indicates that "no migration" will be defined to be concentrations of hazardous constituents below health-based or environmentally based levels at the disposal-unit boundary (US EPA, 1992).

In March 1990, the DOE petitioned the EPA for a "no-migration" determination for a Test Phase for the WIPP (US DOE, 1990d). The DOE submitted the results of modeling to demonstrate, to a reasonable degree of certainty, that the emplaced test wastes would not migrate from the disposal unit during the WIPP Test Phase. The EPA issued a conditional "no-migration" determination, for the WIPP Test Phase only, in November 1990 (US EPA, 1990a). In July 1990 the EPA authorized the State of New Mexico to apply the RCRA regulations to facilities in the state that manage radioactive mixed wastes (US EPA, 1990b). Evaluation strategies are currently being developed for RCRA compliance after the Test Phase is completed. Analyses have been initiated to support evaluations of long-term compliance with the RCRA regulations at the WIPP (WIPP PA Department, 1992).

1.2.3 National Environmental Policy Act (NEPA)

The *National Environmental Policy Act* (NEPA) (Public Law 91-190, 1970, as amended) is enforced by regulations that are not specific regulatory guidelines, but contain a mandate for evaluating the environmental consequences of all significant aspects of a project (US EPA, 1978). The DOE has prepared several environmental impact statements (EISs) that have addressed the predicted experimental, operational, and long-term behavior of the repository (US DOE, 1979, 1980a, 1990c). In addition, the DOE has committed to complete another supplemental EIS at or near the end of the WIPP Test Phase, before disposal in the WIPP may begin. The potential health risks posed by estimated groundwater releases of TRU radionuclides and by direct removal of radionuclides to the surface as a result of drilling have been assessed in the NEPA documentation for the WIPP.

The regulations that implement the NEPA do not specifically require calculating doses of radionuclides to members of the public. However, the WIPP Panel of the National Academy of Sciences, a panel that reviews the scientific basis for the WIPP, has requested safety assessments that present dose calculations for 10,000 years or peak arrival times of radionuclides, whichever occurs first. In accordance with the WIPP Panel's request, preliminary probabilistic safety assessments in which doses have been calculated for hypothetical exposure pathways are part of the analyses that evaluate long-term performance of the WIPP; safety assessments will be prepared periodically.

2. OVERVIEW OF THE DISPOSAL SYSTEM

The characteristics of the WIPP disposal system and its geologic setting are described in detail in other reports (Powers et al., 1978a,b; the WIPP *Final Environmental Impact Statement* [US DOE, 1980a]; Bechtel, 1986; Lappin et al., 1989; the WIPP *Final Safety Analysis Report* [US DOE, 1990b]; and the WIPP *Supplement Environmental Impact Statement* [US DOE, 1990c]). Additional detailed discussion is contained in Volumes 2 and 3 of this report and references cited therein.

2.1 Physical Setting

The WIPP is located in southeastern New Mexico east of the Pecos River and west of the high plains of West Texas, in a region of sand dunes known locally as Los Medaños (The Dunes). Most dunes in the area are stabilized by vegetation, and there is relatively little local topographic relief. Major regional features (Figures 2-1 and 2-2) include Nash Draw, Laguna Grande de la Sal, and the Pecos River.

The land surface within Los Medaños slopes gradually upward to the northeast from Livingston Ridge on the eastern boundary of Nash Draw to a low ridge called "The Divide." Nash Draw, 8 km (5 mi) west of the WIPP, is a broad, shallow topographic depression with no external surface drainage. Nash Draw extends northeast about 35 km (22 mi) from the Pecos River east of Loving, New Mexico, to the Maroon Cliffs area. This feature is bounded on the east by Livingston Ridge and on the west by Quahada Ridge.

Laguna Grande de la Sal, about 9.5 km (6 mi) west-southwest of the WIPP, is a large playa about 3.2 km (2 mi) wide and 4.8 km (3 mi) long, formed by coalesced collapse sinks that were created by dissolution of evaporite deposits. In the geologic past, a relatively permanent, saline lake occupied the playa. In recent history, however, the lake has undergone numerous cycles of filling and evaporation in response to wet and dry seasons, and effluent from the potash and oil and gas industries has enlarged the lake.

The Pecos River, the principal surface-water feature in southeastern New Mexico, flows southeastward, draining into the Rio Grande in western Texas. At its closest point, the river is about 20 km (12 mi) southwest of the WIPP. Surface drainage from the WIPP does not reach the river or its ephemeral tributaries.

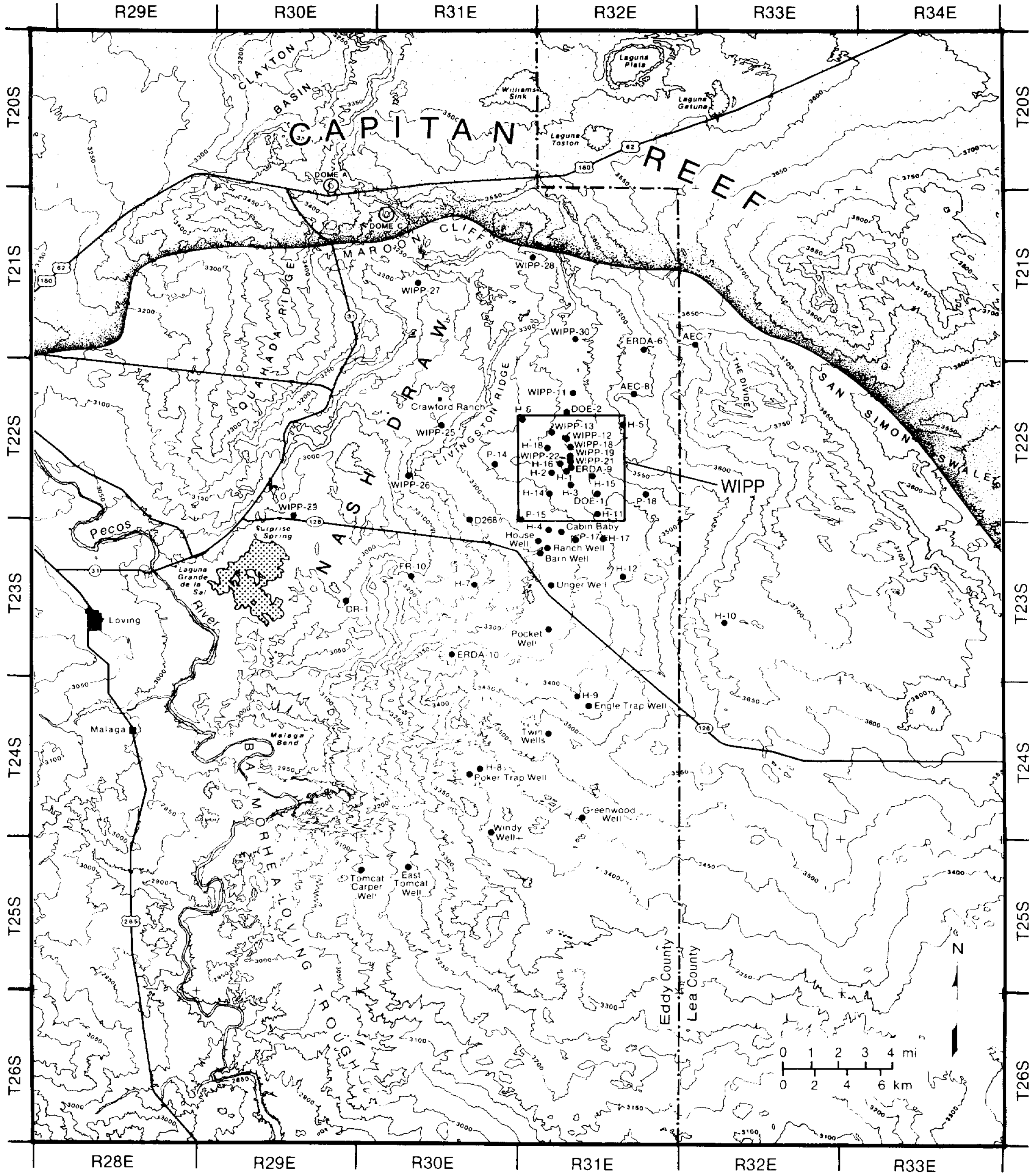

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Figure 2-1. Topographic map of the WIPP area (Bertram-Howery et al., 1990).

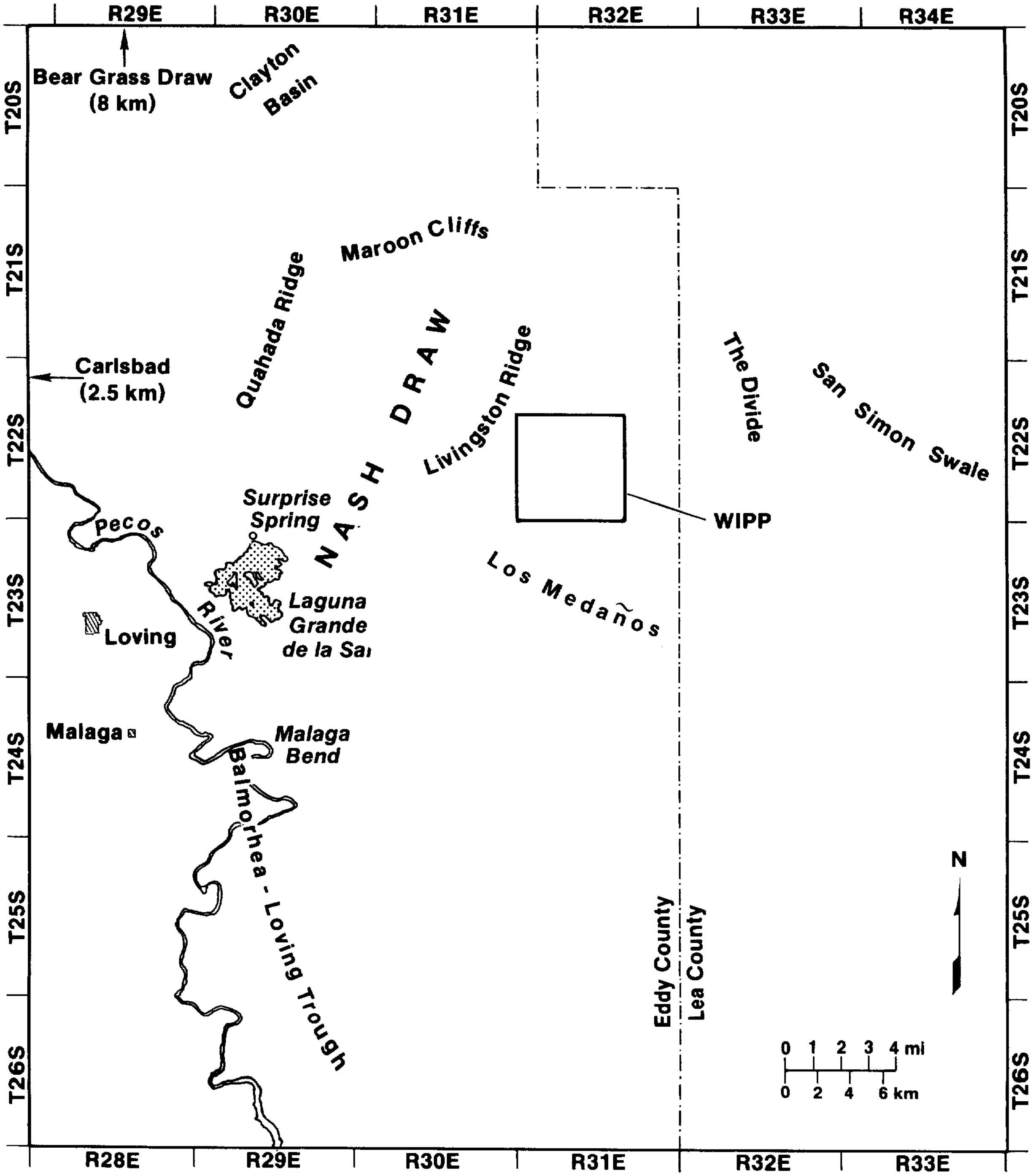


Figure 2-2. Map of the WIPP area, showing physiographic features (Bertram-Howery et al., 1990).

2.2 Natural Resources

Potash, oil, and gas are the only known important mineral resources in the vicinity of the WIPP. Estimates of the volumes and locations of these resources are reported by US DOE (1980a).

About 56 productive oil and gas wells are located within a radius of 16 km (10 mi) from the WIPP; the wells generally tap Pennsylvanian strata, about 4,200 m (14,000 ft) deep. The hydrocarbon well closest to the land-withdrawal boundary is about 3 km (2 mi) to the south-southwest of the waste panels, and has produced natural gas since 1982 (Silva and Channell, 1992). The surface location of the well is outside the land-withdrawal boundary, but the borehole is slanted to withdraw gas from rocks below the WIPP horizon within the boundary. Except for this well, resource extraction is not allowed within the proposed land-withdrawal boundary.

Three potash mines and two associated chemical-processing plants are located between 8 and 16 km (5 and 10 mi) from the WIPP (US DOE, 1990b). As discussed further in Section 2.3 of this volume, potash-enriched beds are found stratigraphically above the repository horizon; neither mining of potash nor exploratory drilling for potash reserves reaches the repository horizon. The nearest economically exploitable potash reserves are approximately 1 km (0.6 mi) from the waste panels (Brausch et al., 1982; Guzowski, 1991).

2.3 Summary of Regional Geology

Geologically, the WIPP is located in the Delaware Basin, which is an elongated depression that extends from just north of Carlsbad, New Mexico, southward into Texas (Figure 2-3). The basin covers over 33,000 km^2 (12,750 mi^2) and is filled with sedimentary rocks to depths as great as 7,300 m (24,000 ft) (Hills, 1984).

2.3.1. Geologic History

The geologic history of the Delaware Basin is described in more detail elsewhere (Hiss, 1975; Powers et al., 1978a,b; Cheeseman, 1978; Williamson, 1978; Hills, 1984; Ward et al., 1986; Harms and Williamson, 1988; Volume 2, Chapter 2 of this report). Rock units of the Delaware Basin representing the Permian System through the Quaternary System are shown in Table 2-1. Simplified stratigraphy at the WIPP is shown in Figure 2-4.

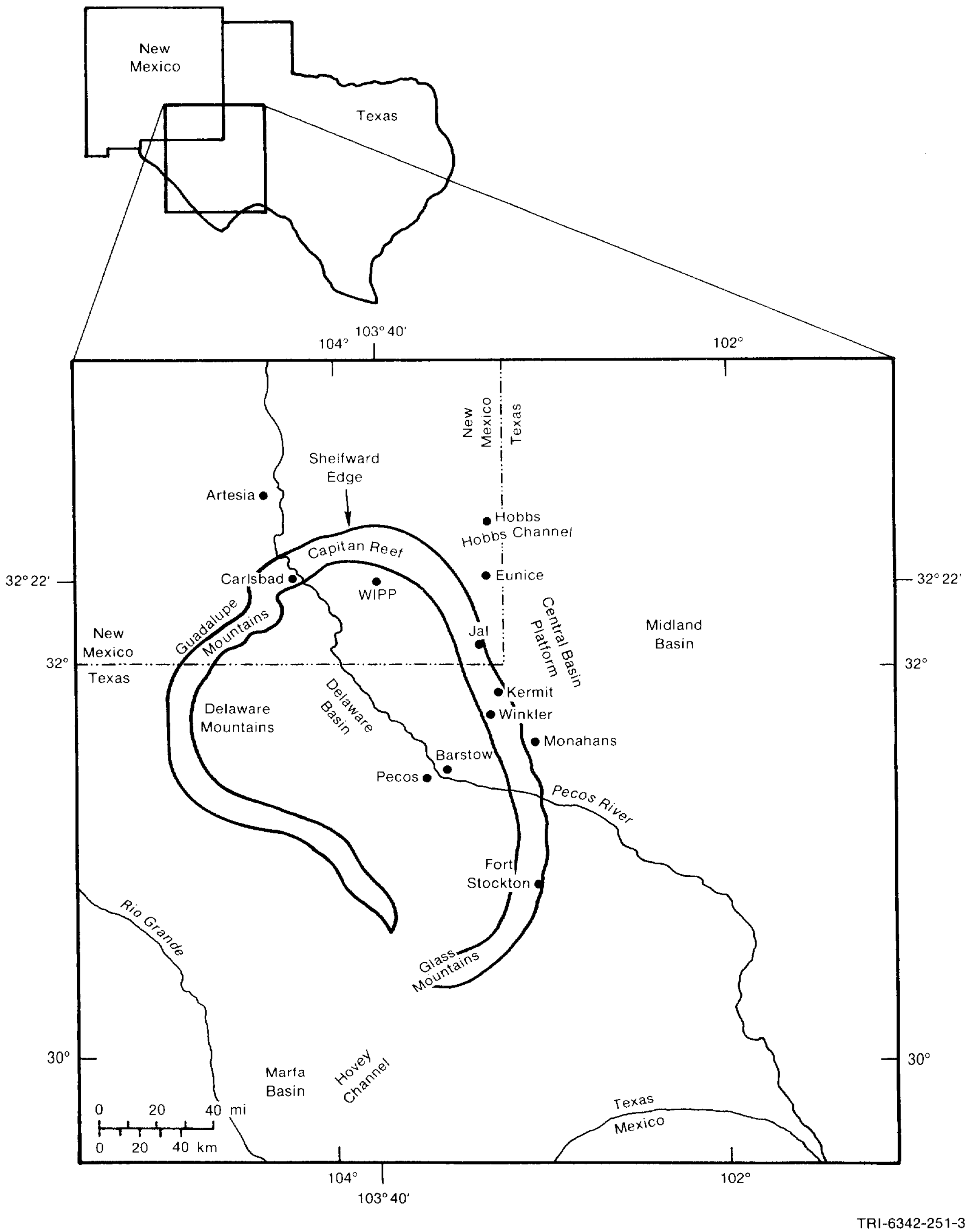


Figure 2-3. Location of the WIPP in the Delaware Basin (modified from Richey et al., 1985).

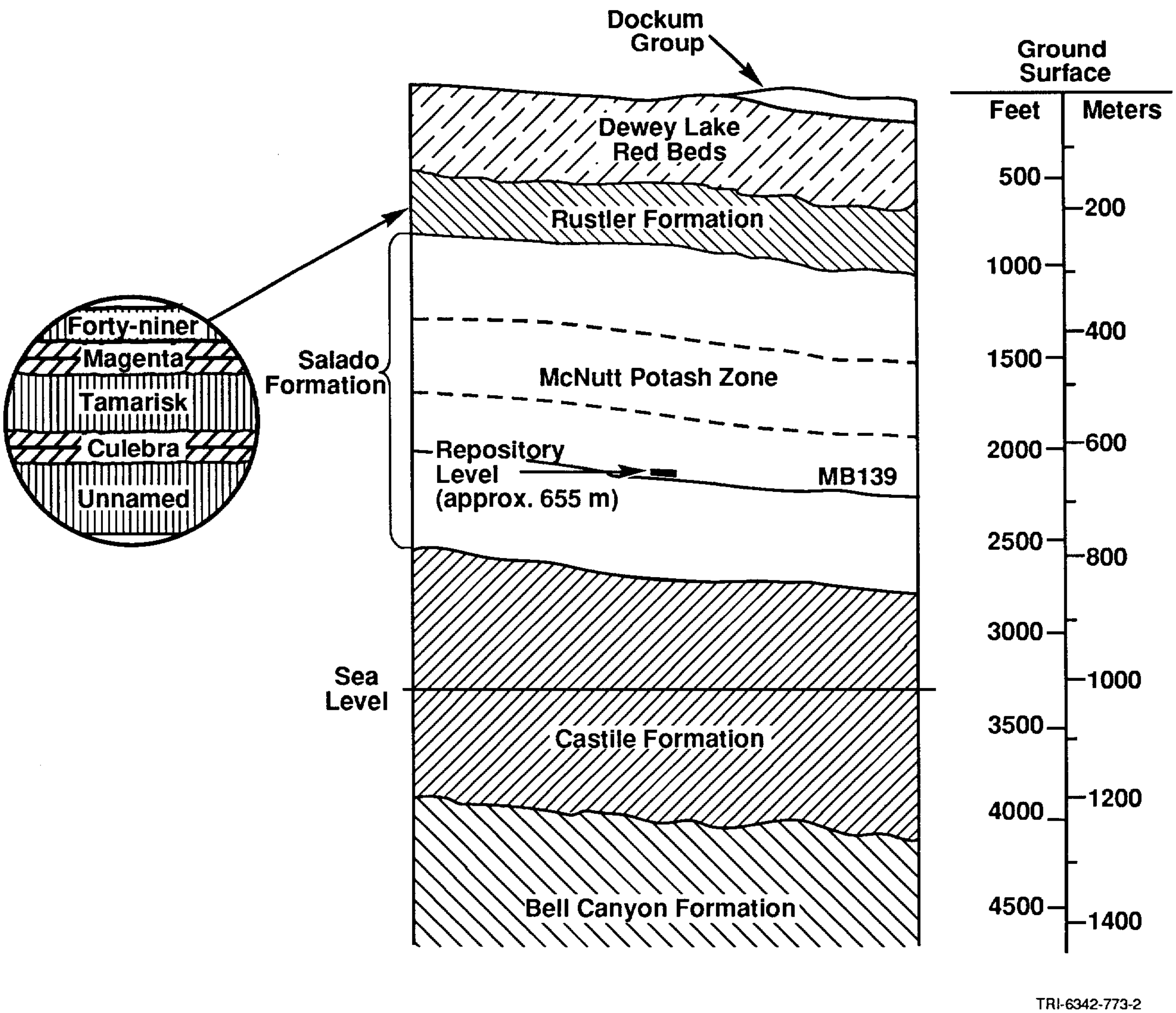


Figure 2-4. Generalized WIPP stratigraphy (modified from US DOE, 1980b).

Table 2-1. Major Stratigraphic Divisions, Southeastern New Mexico

Erathem	System	Series	Lithostratigraphic Unit	Age Estimate (yr)
Cenozoic	Quaternary	Holocene	Windblown sand	
		Pleistocene	Mescalero caliche	~500,000
			Gatuña Formation	~600,000 ±
	Tertiary	Pliocene		
			Ogallala Formation	5.5 million
		Miocene		
				24 million
		Oligocene Eocene Paleocene	Absent in Southeastern New Mexico	
				66 million
Mesozoic	Cretaceous	Upper	Absent in Southeastern New Mexico	
		Lower	Detritus preserved	
				144 million
	Jurassic		Absent in Southeastern New Mexico	
				208 million
	Triassic	Upper	Dockum Group	
		Lower	Absent in Southeastern New Mexico	
				245 million
Paleozoic	Permian — Upper	Ochoan	Dewey Lake Red Beds Rustler Formation Salado Formation Castile Formation	
	Permian — Lower	Guadalupian	Capitan Limestone and Bell Canyon Formation	
		Leonardian Wolfcampian	Bone Springs Wolfcamp (informal)	
				286 million

Source: Modified from Bachman, 1987

The Delaware Basin began forming by crustal subsidence during the Pennsylvanian Period, approximately 300 million years ago. Relatively rapid subsidence during the Early and mid-Permian, between approximately 286 and 260 million years ago, resulted in the deposition of a sequence of deep-water sandstones, shales, and limestones rimmed by shallow-water limestone reefs (Figure 2-3). The thickest of the reef deposits, the Capitan Limestone, is buried under younger rocks north and east of the WIPP but is exposed at the surface in the Guadalupe Mountains to the west. Subsidence slowed during the Late Permian; evaporite deposits of the Castile Formation and the Salado Formation, which hosts the WIPP, filled the basin and extended over the reef margins. Evaporites, carbonates, and clastic rocks of the Rustler Formation and the Dewey Lake Red Beds were deposited above the Salado Formation before the end of the Permian Period.

Beginning with the Triassic Period and continuing to the present, the geologic record for the area indicates long periods of nondeposition or erosion. Those formations that are present are either relatively thin or discontinuous and are not included in the performance assessment of the WIPP. Near the repository, the older, Permian-age deposits below the Dewey Lake Red Beds have not been affected by erosional processes during the past 250 million years (Lappin, 1988).

Minimal tectonic activity has occurred in the region since the Permian Period (Hayes, 1964; Williamson, 1978; Hills, 1984; Powers et al., 1978a). Faulting during the late Tertiary Period formed the Guadalupe and Delaware Mountains along the western edge of the basin. The most recent igneous activity in the area was during the mid-Tertiary Period about 35 million years ago and is evidenced by a dike in the subsurface 16 km (10 mi) northwest of the WIPP (Powers et al., 1978a,b). Major volcanic activity last occurred more than 1 billion years ago during Precambrian time (Powers et al., 1978a,b). None of these processes affected the Salado Formation at the WIPP.

2.3.2 Stratigraphy and Geohydrology

The Bell Canyon Formation of the Delaware Mountain Group is the deepest hydrostratigraphic unit being considered in the performance assessment (Figure 2-4). Understanding hydrologic conditions in the Bell Canyon is potentially important because oil and gas drilling into deeper Pennsylvanian strata could first penetrate the WIPP and brine-saturated sandstones of the Bell Canyon Formation. Available pressure data from wells indicate that brine flow from the Bell Canyon Formation is not a likely mechanism for radionuclide release (Volume 2, Section 2.2.1 of this report), however, and the Bell Canyon Formation is not included explicitly in performance-assessment modeling.

The Castile Formation near the WIPP consists of anhydrite and lesser amounts of halite. The Castile Formation is of interest because it contains discontinuous reservoirs of pressurized brine that could affect repository performance if penetrated by an exploratory borehole. Except where brine reservoirs are present, permeability of the Castile Formation is extremely low, and rates of groundwater flow are too low to affect the disposal system within the next 10,000 years.

The 250-million-year-old Salado Formation, which hosts the repository, is about 600 m (2,000 ft) thick and consists of the following three informal members:

- a lower member, which is mostly halite with lesser amounts of anhydrite, polyhalite, and glauberite, with some layers of fine clastic material. The unit is 296 to 354 m (960 ft to 1160 ft) thick, and the WIPP repository is located within it, 655 m (2,150 ft) below the land surface (Jones, 1978). Anhydrite layers near the WIPP horizon that are modeled in performance assessment include Marker Beds 138 and 139 and anhydrites A and B (Figure 2-5). Because anhydrite is more brittle than halite, fracturing within these interbeds has the potential to provide a pathway for gas and brine (and, therefore, contaminants) to migrate from the repository

- a middle member, the McNutt Potash Zone, which is reddish-orange and brown halite with deposits of sylvite and langbeinite from which potassium salts are mined (Jones, 1978)

- an upper member, which is reddish-orange to brown halite interbedded with polyhalite, anhydrite, and sandstone (Jones, 1978)

These lithologic layers are nearly horizontal at the WIPP, with a regional dip of less than one degree. The Salado Formation has not been disturbed by post-depositional processes in the WIPP area, and groundwater flow within it is extremely slow because primary porosity and open fractures are lacking in the plastic salt (Mercer, 1983). The formation is assumed to be brine-saturated throughout the WIPP area, but low permeability allows for little groundwater movement. The Salado Formation is discussed in more detail in Volumes 2 and 3 of this report.

The Rustler Formation, the youngest formation of the Late Permian evaporite sequence, includes units that provide potential pathways for radionuclide migration away from the WIPP. The following five units of the Rustler, in ascending order, have been described (Vine, 1963; Mercer, 1983):

- an unnamed lower member, composed mostly of fine-grained, silty sandstones and siltstones interbedded with anhydrite west of the WIPP but with increasing amounts of halite to the east

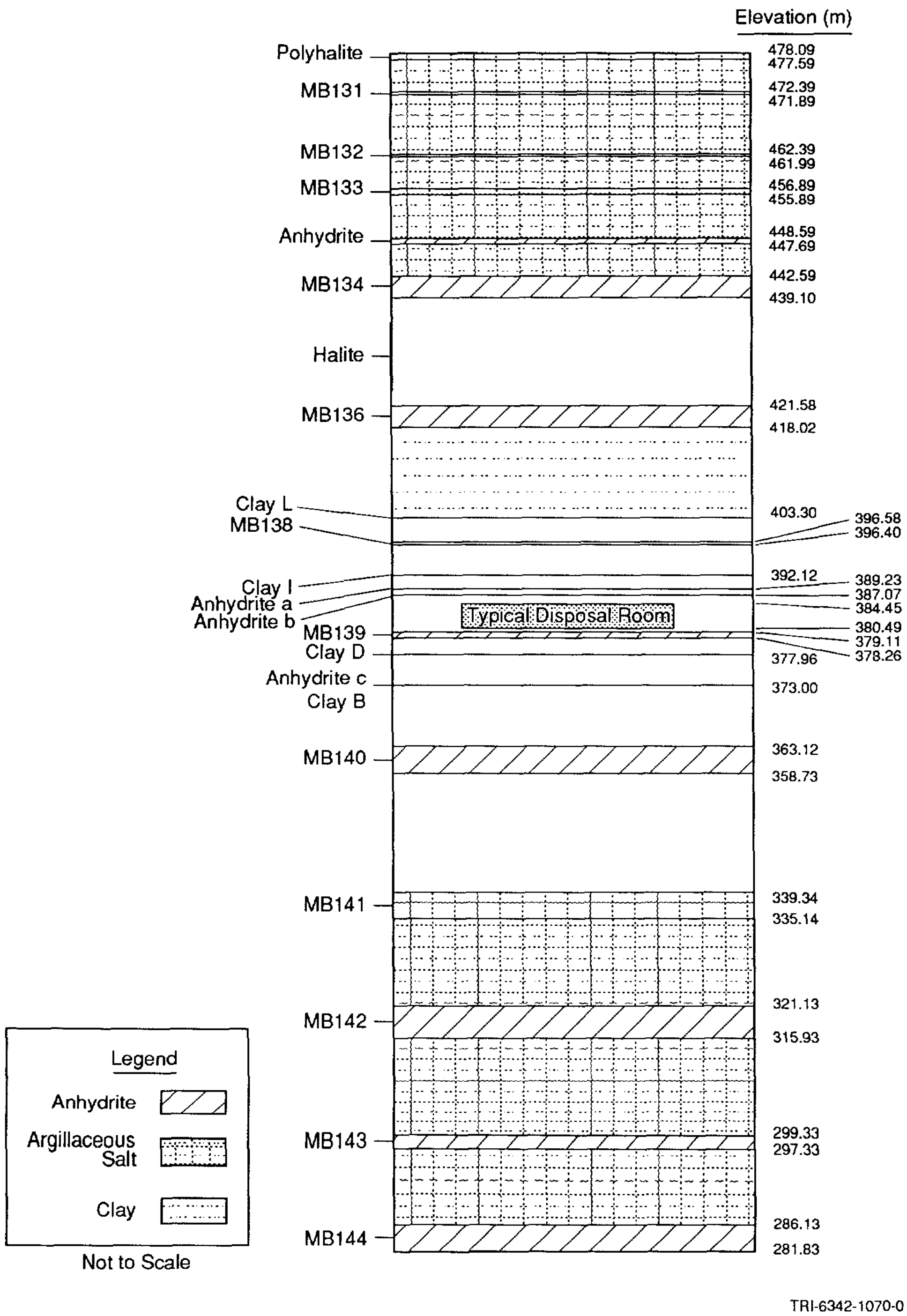


Figure 2-5. Reference local stratigraphy near repository (after Munson et al., 1989a, Figure 3-3; elevations from Bechtel, 1986).

- the Culebra Dolomite Member, a microcrystalline, grayish dolomite or dolomitic limestone with solution cavities containing some gypsum and anhydrite filling

- the Tamarisk Member, composed of anhydrite interbedded with thin layers of claystone and siltstone, with some halite east of the WIPP

- the Magenta Dolom. e Member, a very-fine-grained, greenish-gray dolomite with reddish-purple layers

- the Forty-niner Member, consisting of anhydrite interbedded with a layer of siltstone, with halite present east of the WIPP

Most groundwater flow in the Rustler Formation occurs in the Culebra Dolomite and Magenta Dolomite Members. The intervening units (the unnamed lower member, the Tamarisk Member, and the Forty-niner Member) are considered aquitards because of their low permeability throughout the area.

Groundwater flow in the Culebra Dolomite Member near the WIPP is north to south (see Volume 2, Chapter 2 of this report). Recharge apparently occurs north of the WIPP, possibly at Bear Grass Draw where the Rustler Formation is near the surface and at Clayton Basin where karst activity has disrupted the Culebra Dolomite (Mercer, 1983). Discharge occurs west-southwest of the WIPP, either into the Pecos River at Malaga Bend (Hale et al., 1954; Hale and Clebsch, 1958; Havens and Wilkens, 1979; Mercer, 1983), or into Cenozoic alluvium in the Balmorhea-Loving Trough, which is a series of coalesced, lens-shaped solution troughs formed by an ancestral Pecos River, or into both (Brinster, 1991). Culebra water near the WIPP contains large concentrations of total dissolved solids (Siegel et al., 1991). Currently, no wells in the WIPP vicinity produce water from the Culebra for human consumption. The nearest well that has produced water from the Culebra for livestock is 6 km (4 mi) from the waste panels (Bodine et al., 1991).

Small amounts of water can be produced from the Magenta Dolomite Member from a thin, silty dolomite, along bedding planes of rock units, and along fractures (Mercer, 1983). Regionally, the direction of groundwater flow is similar to that in the Culebra, either toward Malaga Bend or more directly southward to the Balmorhea-Loving Trough. Near the WIPP, available well data indicate that flow in the Magenta is locally from east to west, perpendicular to flow in the Culebra (see Section 2.2.3.6 of Volume 2 of this report). No wells in the WIPP vicinity produce water from the Magenta for human or livestock consumption.

Overlying the Rustler Formation are the Dewey Lake Red Beds, which are the youngest Permian rocks and which consist of alternating layers of reddish-brown, fine-grained sandstone and siltstone cemented with calcite and gypsum (Vine, 1963). Several wells in the WIPP area produce small amounts of water from the Dewey Lake Red Beds for livestock (Cooper and Glanzman, 1971). The closest such well is at the J.C. Mills (James) Ranch, 4 km (2.5 mi) south of the waste panels. In general, however, the unit is not a productive source of water; drilling has identified only a few localized zones of relatively high permeability (Mercer, 1983; Beauheim, 1987a).

From the WIPP eastward, the Dewey Lake Red Beds are unconformably overlain by Triassic rocks of the undifferentiated Dockum Group (Figure 2-4). The lower Dockum is composed of poorly sorted, angular, coarse-grained to conglomeratic, thickly bedded clastic material interfingering with shales. At the WIPP, the unit is relatively thin (approximately 10 m [33 ft] thick), and unsaturated. Further east, where the Triassic rocks are thicker, they are the chief source of water for domestic and livestock use in eastern Eddy County and western Lea County (Nicholson and Clebsch, 1961; Richey et al., 1985). Recharge to the Triassic rocks is mainly downward flow from overlying alluvium.

No rocks of Jurassic or Cretaceous age are present east of the Pecos River near the WIPP. The Tertiary Period is represented by a thin remnant of the Ogallala Formation at The Divide west of San Simon Swale. The Quaternary Period is represented by discontinuous sandstones and conglomerates of the Gatuña Formation, the informally named Mescalero caliche, and localized accumulations of alluvium and dune sands (Bachman, 1980, 1984; Mercer, 1983).

2.4 Repository/Shaft System

The WIPP repository is about 655 m (2,150 ft) below the land surface in bedded salt of the Salado Formation. Present plans call for mining eight panels of seven rooms each and two equivalent panels in the central drifts (Figure 2-6 and 2-7). As each panel is filled with waste, the next panel will be mined. Before the repository is closed permanently, each panel will be backfilled and sealed, waste will be placed in the drifts between the panels and backfilled, to create two additional panel volumes, and access ways will be sealed off from the shafts. Because the WIPP is a research and development facility, an extensive experimental area is also in use north of the waste-disposal area (US DOE, 1990a). Additional information on the repository design is in Volumes 2 and 3 of this report.

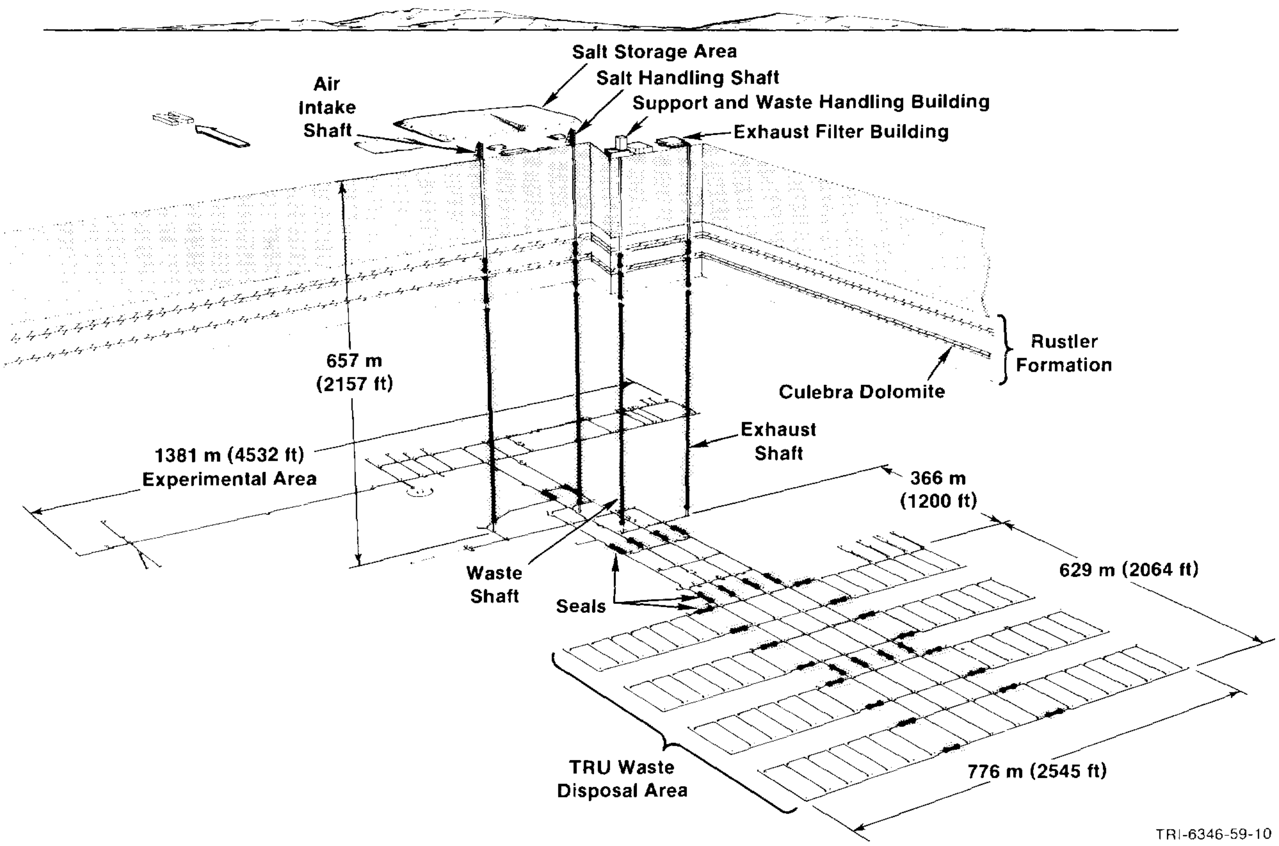


Figure 2-6. Proposed WIPP repository, showing both TRU-waste disposal areas and experimental areas (after Waste Management Technology Dept., 1987).

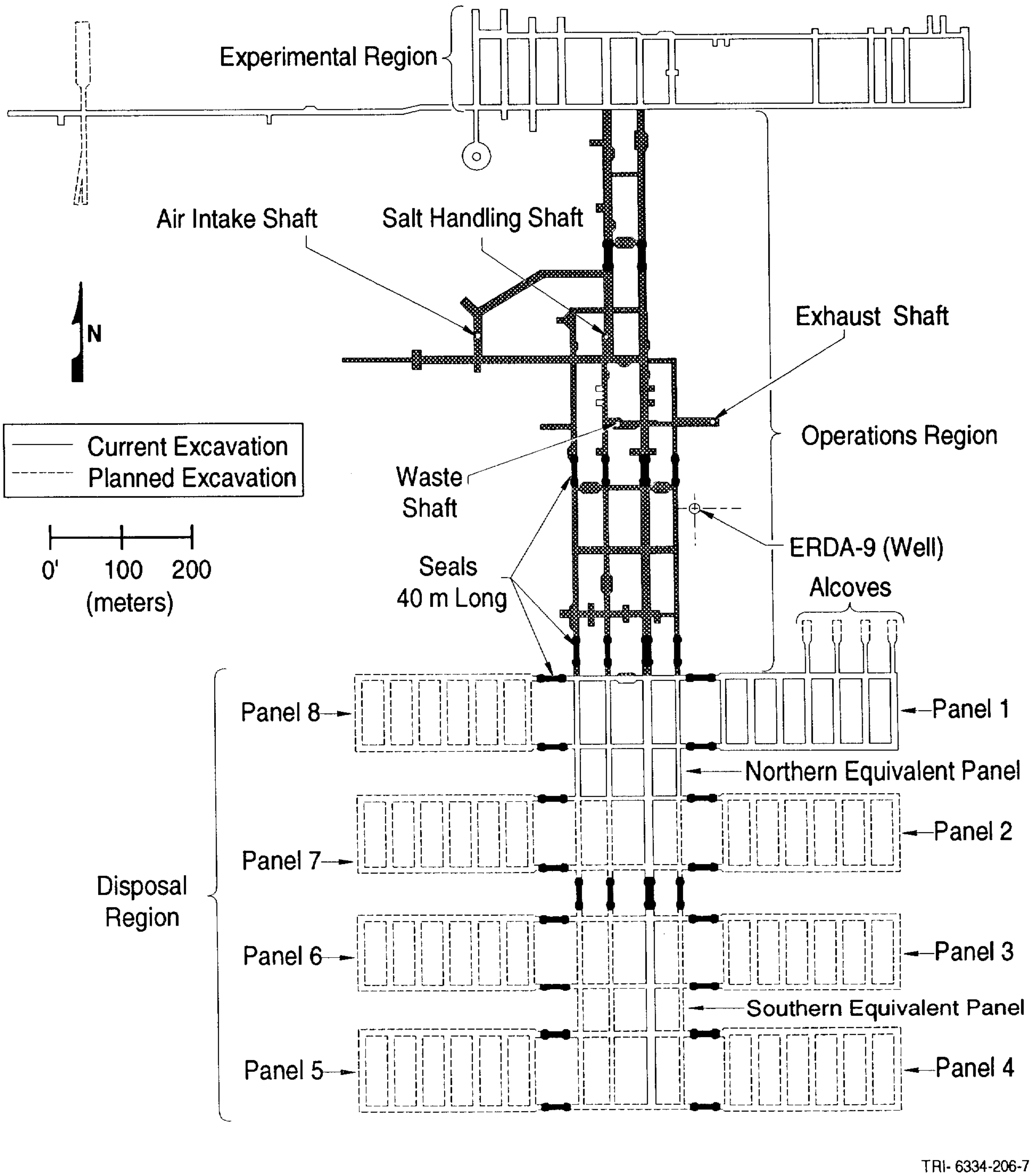


Figure 2-7. Excavated areas and planned seals in the WIPP repository (modified from Bechtel, 1986; Nowak et al., 1990).

2.5 Waste

As noted in Section 1.1.2 of this volume, the WIPP is designed for transuranic waste generated by United States government defense-related activities since 1970. The waste consists of laboratory and production materials such as glassware, metal pipes, sorbed or solidified spent solvents, disposable laboratory clothing, cleaning rags, and solidified sludges. Along with other contaminants, the waste is contaminated by alpha-emitting transuranic (TRU) elements with atomic numbers greater than 92 (uranium), half-lives greater than 20 years, and curie contents greater than 100 nCi/g. Additional contaminants include other radionuclides of uranium and several contaminants with half-lives less than 20 years. Approximately 60 percent of the TRU waste may be co-contaminated with hazardous constituents as defined under the Resource Conservation and Recovery Act (RCRA). The waste scheduled for disposal in the WIPP is described in more detail in Volume 3 of this report.

In accordance with DOE Order 5820.2A (US DOE, 1990a), heads of DOE Field Organizations can determine that other alpha-contaminated wastes, peculiar to a specific waste-generator site, must be managed as TRU wastes. The WIPP Waste Acceptance Criteria (WAC) determine which TRU wastes will be accepted for emplacement in the WIPP (US DOE, 1991a). Under current plans, most TRU waste generated since 1970 will be disposed of in the WIPP, but some will be disposed of on-site at other DOE facilities. Inventories of the waste to be disposed of in the WIPP are in Volume 3 of this report.

2.5.1 Waste Form

Alpha-emitting TRU waste, although dangerous if inhaled or ingested, is not dangerous externally and can be handled safely if confined in a sealed container. Most of the waste, therefore, can be contact handled (CH) because the external dose rate (200 mrem/h or less) permits people to handle properly sealed drums and boxes without any special shielding. The only containers that can currently be shipped to the WIPP in a TRUPACT-II truck-transport container (NuPac, 1989) are 55-gallon steel drums, metal standard waste boxes (SWBs), 55-gallon drums overpacked in an SWB, and an experimental bin overpacked in an SWB (US DOE, 1990c). Additional information on waste containers is in Volume 3 of this report.

A portion of the TRU waste must be remotely handled (RH). Because the surface dose rate exceeds 200 mrem/h, the waste canisters must be packaged for handling and transportation in specially shielded casks. The surface dose rate of RH-TRU canisters cannot exceed 1,000 rem/h, and no more than 5 percent of the canisters can exceed 100 rem/h. RH-TRU waste in canisters will be emplaced in holes drilled into the walls of the rooms (US DOE, 1990b).

As stated in the *WIPP Land Withdrawal Act* (Public Law 102-579, 1992), the WIPP's current design capacity for all radionuclides is 6.2 million ft^3 (approximately 175,600 m^3), of which no more than 5.1 million curies (Ci) may be RH-TRU waste. The complex analyses for evaluating regulatory compliance require knowledge of the waste inventory. Therefore, all analyses will be based on current projections of a design volume inventory, estimated at about 532,500 drums and 33,500 boxes of CH-TRU waste (WIPP PA Division, 1991c). The wastes are classified as either retrievably stored or newly generated (future generated). Additional information on inventory estimates is in Volume 3 of this report.

A hazardous constituent of CH-TRU waste is lead that is present as incidental shielding, glovebox parts, and linings of gloves and aprons. Trace quantities of mercury, barium, chromium, silver, and cadmium have also been reported (US DOE, 1990d). Estimates of the quantities of metals and combustibles are discussed in Volume 3 of this report. Sludges may contain a solidifier (such as cement), absorbent materials, inorganic compounds, complexing agents, and organic compounds including oils, solvents, alcohols, emulsifiers, surfactants, and detergents. The WAC (US DOE, 1991a) waste-form requirements state that the waste material shall be immobilized if greater than 1 percent by weight is particulate material less than 10 microns in diameter or if greater than 15 percent by weight is particulate material less than 200 microns in diameter. Only residual liquids in well-drained containers (e.g., bottles, cans, etc.) in quantities less than approximately 1 percent of the container's volume are allowed. The total liquid shall be less than one volume percent of the waste container (e.g., drum or SWB). Radionuclides in pyrophoric form are limited to less than 1 percent by weight of the waste package, and no explosives or compressed gases are allowed. These hazardous constituents are not regulated under 40 CFR Part 191, but some are regulated separately by the EPA and New Mexico under the *Resource Conservation and Recovery Act* (RCRA). Many of these chemicals (hazardous and nonhazardous), if present in significant quantities, could affect the ability of radionuclides to migrate out of the repository by influencing rates of degradation of the organics, microbial activity, and gas generation. The effects of these processes are being studied.

2.5.2 Radionuclide Inventory

The radionuclide composition of CH- and RH-TRU waste varies depending upon the facility and process that generate the waste. An estimate of the CH- and RH-TRU radionuclide inventories is in Volume 3 of this report.

The fissile material content in equivalent grams of plutonium-239 allowed by the WAC for CH-TRU waste is less than 200 g for a 55-gallon drum and less than 25 g for a SWB. It is expected that the fissile material for TRU waste in a remotely handled cask will be limited to less than 325 g (US DOE, 1991a).

As discussed further in Section 3.3.2 of this volume, the EPA has set cumulative release limits in curies per 10,000 years for isotopes of americium, carbon, cesium, iodine, neptunium, plutonium, radium, strontium, technetium, thorium, tin, and uranium, as well as for certain other radionuclides (Appendix A of 40 CFR 191, Subpart B). Although the initial WIPP inventory contains little or none of some of the listed nuclides, they will be produced as a result of radioactive decay and must be accounted for in the compliance evaluation. Moreover, for compliance with the Individual Protection Requirements of 40 CFR 191, Subpart B, any radionuclides not listed in Appendix A must be accounted for if those radionuclides could contribute to doses.

2.5.3 Possible Modifications to Waste Form

If ongoing research does not establish sufficient confidence in acceptable performance or indicates a potential for unacceptable performance, modifications to the waste form or backfill could be required. SNL has conducted preliminary research on possible modifications (Butcher, 1990). The Engineered Alternatives Task Force (EATF) identified specific alternatives, ranked alternatives according to specific feasibility criteria, and recommended further research (US DOE, 1990e, 1991b). The DOE will make decisions about testing and, if necessary, implementing alternatives based on the recommendations of the EATF and performance-assessment considerations provided by SNL.

3. APPLICATION OF 40 CFR PART 191, SUBPART B, TO THE WIPP

The radioactive-waste disposal regulations, *40 CFR Part 191—Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (US EPA, 1985), referred to in this volume of the report as the Standard, are divided into two subparts.

Subpart A limits the radiation doses that may be received by members of the public in the general environment (see Section 3.2.2 of this volume), as a result of management and storage of TRU wastes at DOE disposal facilities not regulated by the Nuclear Regulatory Commission (NRC). Subpart A requires that "the combined annual dose equivalent to any member of the public in the general environment resulting from discharges of radioactive material and direct radiation from such management and storage shall not exceed 25 millirems to the whole body and 75 millirems to any critical organ" (§ 191.03(b)). Subpart A does not apply to long-term disposal of radioactive wastes. Subpart A is discussed in the ***Technical Needs Assessment*** report (US DOE, 1992a), and in the "Test Phase Plan" currently being prepared by the DOE. Except for discussion of a few terms that are important in understanding Subpart B, Subpart A is not considered further in this report.

Subpart B of the Standard (Figure 3-1) specifies probabilities of cumulative releases of radionuclides to the accessible environment (see Section 3.2.2 of this volume) for 10,000 years (Containment Requirements, § 191.13) and annual radiation dose limits to members of the public in the accessible environment for 1000 years (Individual Protection Requirements, § 191.15) as a result of TRU-waste disposal. Actions and procedures are required to increase confidence that the probabilistic release limits specified in the Containment Requirements will be met (Assurance Requirements, § 191.14). Radioactive contamination of certain sources of groundwater near the WIPP disposal system from such TRU wastes is also regulated (Groundwater Protection Requirements, § 191.16), if any of these sources of groundwater are found to be present (US DOE, 1989). Each of the four requirements of Subpart B and their method of evaluation by the WIPP Project are discussed in this chapter.

Subpart B of the Standard was vacated and remanded to the EPA by the United States Court of Appeals for the First Circuit in July 1987 (NRDC v. US EPA, 1987). A proposed revision of the Standard was prepared for discussion within the EPA in February 1992. The ***WIPP Land Withdrawal Act*** (Public Law 102-579, 1992) reinstated those portions of the 40 CFR 191,

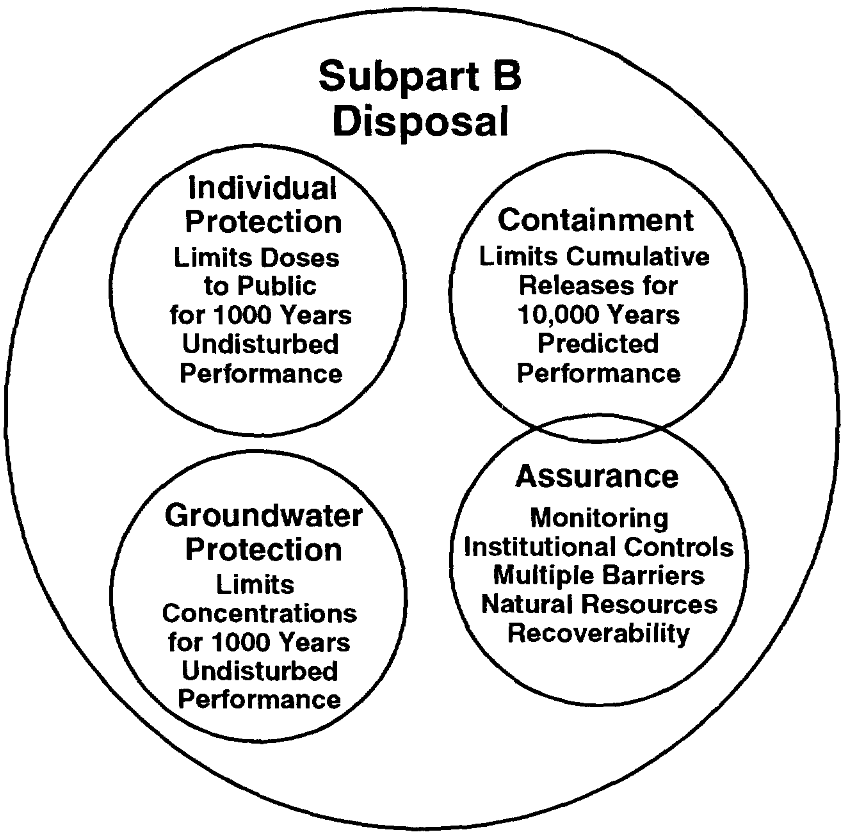


Figure 3-1. Graphical representation of Subpart B of *40 CFR Part 191—Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (after US DOE, 1989). The overlapping of the Assurance Requirements with the Containment Requirements indicates that the Assurance Requirements specify actions and procedures to increase confidence that the probabilistic release limits in the Containment Requirements will be met.

Subpart B that were not the subject of the remand, and requires the EPA to repromulgate the standard by April 30, 1993, with appropriate revisions to §191.15 and §191.16. The Second Modification to the Consultation and Cooperation Agreement (US DOE and State of New Mexico, 1981, as modified) commits the WIPP Project to proceed with compliance planning using the Standard as first promulgated until a revised Standard becomes available. Therefore, this report discusses the Standard as first promulgated. Compliance plans for the WIPP will be revised as necessary in response to changes in the Standard resulting from the repromulgation. The current DOE approach to compliance with the Standard is described in the WIPP *Compliance Strategy* (US DOE, 1989; also see US DOE, 1990d). Additional discussion of some aspects of the current compliance approach is in the *Technical Needs Assessment* report (US DOE, 1992a), and in the "Test Phase Plan" currently being prepared by the DOE.

The full text of the Standard is reproduced as Appendix A of this volume.

3.1 Guidance for Implementation of the Standard

Appendix B of the Standard is EPA's guidance to the implementing agency (in this case, the DOE). Although it is not formal regulatory criteria within the Standard, Appendix B describes the EPA's assumptions regarding the implementation of Subpart B. In the supplementary information published with the Standard, the EPA states that it intends the guidance to be followed:

> "...Appendix B...describes certain analytical approaches and assumptions through which the [EPA] intends the various long-term numerical standards of Subpart B to be applied. This guidance is particularly important because there are no precedents for the implementation of such long-term environmental standards, which will require consideration of extensive analytical projections of disposal system performance" (US EPA, 1985, p. 38069).

The EPA based Appendix B on analytical assumptions it used to develop the technical basis for the numerical disposal standards. Thus, the EPA "believes it is important that the assumptions used by the [DOE] are compatible with those used by EPA in developing this rule. Otherwise, implementation of the disposal standards may have effects quite different than those anticipated by EPA" (US EPA, 1985, p. 38074).

3.2 Terminology

The concept of "site" is integral to limits established by Subparts A and B for releases of radionuclides from the repository, during disposal, decommissioning, and post-closure phases. "Site" is used differently in the two subparts. The differences in the meaning of "site" for the two subparts must be understood in order to avoid confusion in applying the Standard to the WIPP. The definitions of "general environment," "accessible environment," and "controlled area," which are also important in assessing compliance with the Standard, depend on the definition of "site." "Site" has also been used generically for many years by the waste-management community (e.g., in the phrases "site characterization" or "site specific"); few uses of the word correspond to either of the EPA's usages in the Standard (Bertram-Howery and Hunter, 1989a; also see US DOE, 1989). Other terms that are important in understanding the application of the Standard to the WIPP also are explained in this section.

3.2.1 "Site"

The "**site**" as defined for Subpart A is "an area contained within the boundary of a location under the effective control of persons possessing or using...radioactive waste that are involved in any activity, operation, or process covered by this Subpart" (§ 191.02(n)). **Site** for the purposes of Subpart A of the WIPP is the secured-area boundary shown in Figure 1-2. This area will be under the effective control of the security force at the WIPP, and only authorized persons will be allowed within the boundary (US DOE, 1989). In addition, the DOE has control over the area contained within the land-withdrawal boundary, designated by the U.S. Congress (Public Law 102-579, 1992) as the 16 sections (16 mi^2 [41 km^2]) shown in Figure 1-2. The land-withdrawal boundary is referred to in the agreement with New Mexico (US DOE and State of New Mexico, 1981, as modified) and in the WIPP *Final Safety Analysis Report* (US DOE, 1990b) as the "WIPP **site** boundary." Control by the DOE prohibits habitation within the land-withdrawal boundary. Consequently, for the purposes of assessing operational doses to nearby residents for Subpart A, the assumption can be made that no one lives closer than the latter boundary (Bertram-Howery and Hunter, 1989a).

The term "disposal **site**" is used frequently in Subpart B and in Appendix B of the Standard, although it is not defined in the regulation. The **site** for the purposes of Subpart A and the "disposal **site**" for the purposes of Subpart B are not the same. For the purposes of the WIPP strategy for compliance with Subpart B, the "disposal **site**" and the "controlled area" (defined in Section 3.2.3) are the same (US DOE, 1989).

The boundary indicated as "WIPP" on illustrations in this volume is the boundary of the land-withdrawal area and is the same as the "controlled area" boundary used in the 1992 preliminary performance assessment of the WIPP. The subsurface projection of the land-withdrawal boundary within the Salado Formation also forms the lateral boundary of the disposal-unit for evaluating compliance with 40 CFR 268.6 (US EPA, 1990a).

3.2.2 "General Environment" and "Accessible Environment"

The term **"general environment"** is used in Subpart A and is defined as the "total terrestrial, atmospheric, and aquatic environments outside sites within which any activity, operation, or process associated with the management and storage of...radioactive waste is conducted" (§ 191.02(o)). **"Accessible environment"** is used in Subpart B and is defined as "...(1) the atmosphere; (2) land surfaces; (3) surface waters; (4) oceans; and (5) all of the lithosphere that is beyond the controlled area" (see Section 3.2.3) (§ 191.12(k)).

3.2.3 "Controlled Area"

The **"controlled area"** as defined in Subpart B of the Standard is

> "(1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location" (§ 191.12(g)).

The **controlled area** is limited to the lithosphere and the surface within no more than 5 km (approximately 3 mi) from the outer boundary of the WIPP waste-emplacement panels. The boundary of this maximum-allowable **controlled area** does not coincide with the secured-area boundary (Figure 1-2) or with the land-withdrawal boundary (Figure 3-2). According to the definition of "accessible environment," the surface of the **controlled area** is in the accessible environment; the underlying subsurface of the **controlled area** is not part of the accessible environment (Figure 3-2). Any radionuclides that reached the surface would be subject to the limits, as would any that reached the lithosphere outside the subsurface portion of the **controlled area**.

The surface of the **controlled area** is to be identified by passive institutional controls, including permanent markers designating the "disposal site." Additional passive institutional controls are public

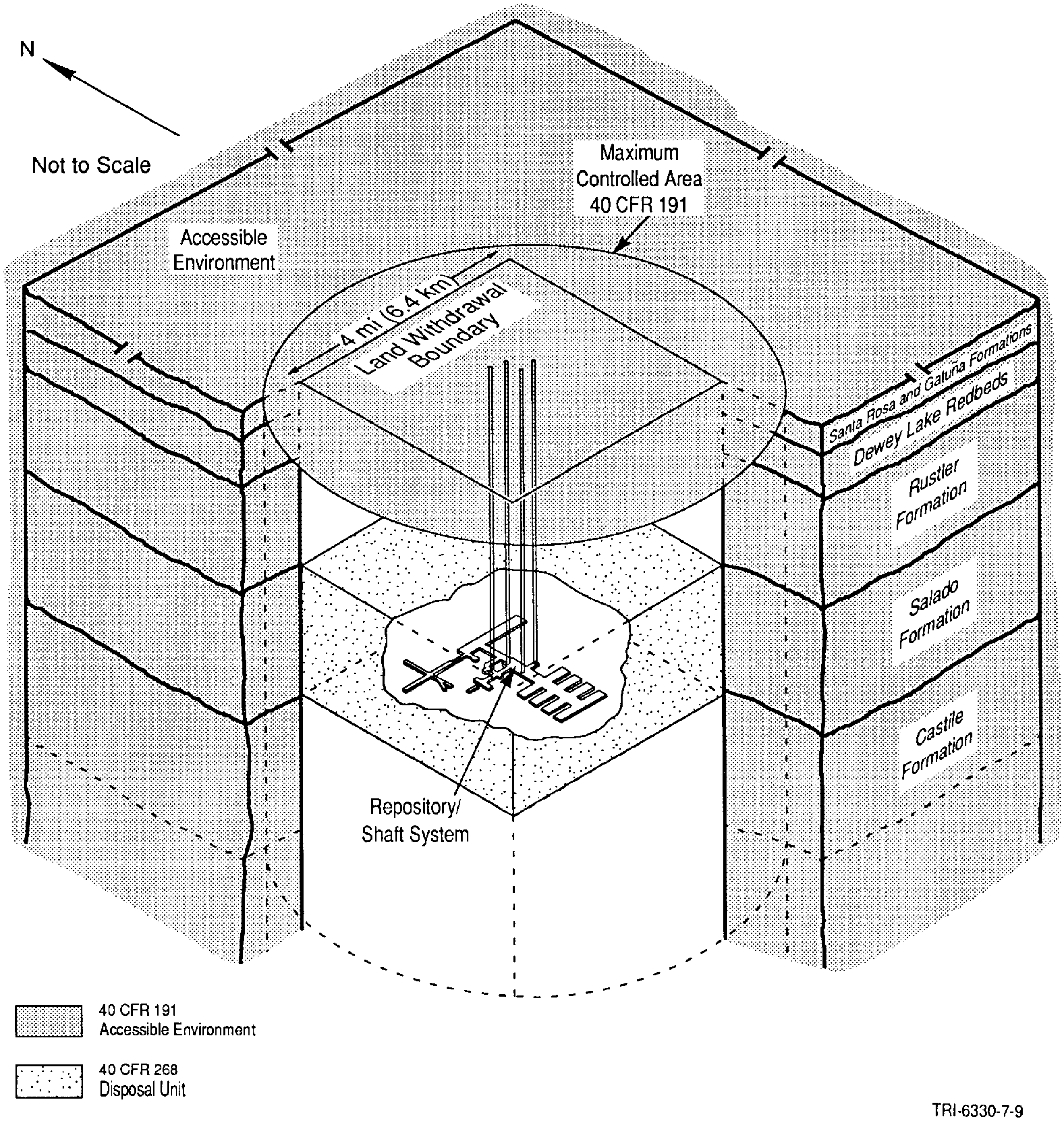


Figure 3-2. Artist's concept of the WIPP disposal system showing the controlled area and accessible environment for 40 CFR 191, Subpart B, and the repository/shaft system. The repository/shaft system scale is exaggerated. On the land surface, the land-withdrawal boundary is shown at the same scale as the maximum extent of the controlled area (modified from Bertram-Howery and Hunter, 1989b). The disposal-unit boundaries for 40 CFR 268 for the WIPP Test Phase are shown for reference (US EPA, 1990a).

records, government ownership, and other methods of preserving knowledge about the disposal system (see Section 3.2.4). Permanent markers and other passive institutional controls are intended to indicate the dangers of the wastes and their location (§ 191.12(e); § 191.12(g)).

3.2.4 "Disposal System" and "Barriers"

The Standard defines "**disposal system**" to mean "any combination of engineered and natural barriers that isolate...radioactive waste after disposal" (§ 191.12(a)). Additionally,

> "'[b]arrier' means any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment. For example, a barrier may be a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around waste, provided that the material or structure substantially delays movement of water or radionuclides" (§ 191.12(d).

For the WIPP, the **disposal system** is the combination of the engineered **barriers** of the repository/shaft system and the natural **barriers** of the "disposal site" (Figure 3-2) that isolate the wastes from the accessible environment. The engineered barriers are seals in drifts and panel entries' backfill in drifts and panels, seals in shafts, and plugs in boreholes. Engineered modifications to the repository design could include making the waste itself form a **barrier**. Natural **barriers** are the subsurface geologic and hydrologic systems within the controlled area that inhibit release and migration of hazardous materials. **Barriers** are not limited to the examples given in the Standard's definition, nor are those examples mandatory for the WIPP. As recommended by the EPA in Appendix B, "...reasonable projections for the protection expected from all of the engineered and natural barriers...will be considered" (US EPA, 1985, p. 38088). No portion will be disregarded, unless that portion of the system makes a "negligible contribution to the overall isolation provided" by the WIPP (US DOE, 1989).

3.3 Containment Requirements

The primary objective of Subpart B is "to isolate most of the wastes from man's environment by limiting long-term releases and the associated risks to populations" (US EPA, 1985, p. 38070). This objective is reflected quantitatively in the Containment Requirements (§ 191.13).

3.3.1 Performance Assessment

Quantitatively evaluating compliance with the Containment Requirements requires a performance assessment, which has specific meaning within the Standard:

> "'Performance assessment' means an analysis that: (1) identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable" (§ 191.12(q)).

Identification of processes and events that might affect the disposal system is part of scenario development and screening for the WIPP and is discussed in Chapter 4 of this volume and Volume 2 of this report. Examining the effects of the processes and events and estimating cumulative releases of radionuclides are part of the performance-assessment consequence modeling and are also discussed in Chapter 4 of this volume and Volume 2 of this report.

The Containment Requirements state that performance must be measured in probabilistic terms. The allowable radionuclide release is not a single, fixed quantity, but rather is a function of the probability that the events and parameter values that contribute to the release will occur (Bertram-Howery and Swift, 1990). Specifically,

> "cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:
>
> (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A) [see Section 3.3.2 of this volume], and
>
> (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A) [see Section 3.3.2 of this volume]" (§ 191.13(a)).

Numerical limits have been placed not on the predicted cumulative radionuclide releases, but rather on the probability that cumulative releases will exceed quantities calculated as prescribed.

With the minor modifications of a 1000-year time period and the addition of a water withdrawal well to provide a potential pathway for radionuclides to reach humans, the performance-assessment methodology developed for the Containment Requirements can be used to assess compliance with undisturbed performance for the Individual Protection Requirements (see Section 3.5 and Chapter 4 of this volume). This volume will refer to the assessment of compliance with both § 191.13(a) of the Containment Requirements and the Individual Protection Requirements as the "performance assessment."

3.3.2 Release Limits

Appendix A of the Standard establishes release limits for all regulated radionuclides. Table 1 in that appendix gives the limit for cumulative releases to the accessible environment for 10,000 years after disposal for each radionuclide per unit of waste. Note 1(e) to Table 1 defines the unit of waste as an amount of TRU wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years. Note 2(b) describes how to develop release limits for a TRU-waste disposal system by determining the waste-unit factor, which is the inventory (in curies) of transuranic alpha-emitting radionuclides in the wastes with half-lives greater than 20 years, divided by one million curies, where transuranic is defined as radionuclides with atomic weights *greater* than 92 (uranium). Consequently, as currently defined in the Standard, all radioactivity in the wastes cannot be included when calculating the waste-unit factor, and release limits are lower than they would be if the waste-unit factor were based on the entire inventory. For the WIPP, 4.3×10^6 curies of the 1992 radioactivity design total of 10.0×10^6 curies are estimated to come from transuranic alpha-emitting radionuclides with half-lives greater than 20 years (memorandum by Peterson in Volume 3, Appendix A of this report). This number is based on the design radionuclide inventories by waste generator for contact-handled (CH) and remotely handled (RH) TRU wastes (see memorandum by Peterson in Volume 3, Appendix A of this report). By definition, isotopes of uranium (atomic weight of 92) and those that are short-lived (half-lives less than 20 years) cannot be included in determining the waste-unit factor. The most important such isotope for the WIPP is Pu-241, which has a half-life of 14.4 years (see Volume 3 of this report). Although Pu-241 and other isotopes in the design radionuclide inventories cannot be included in calculating the waste-unit factor, performance assessments for the WIPP do consider these radionuclides and their decay products in consequence calculations.

Note 6 of Table 1 in the Standard's Appendix A describes the manner in which the release limits are to be used to determine compliance with § 191.13(a): for each radionuclide released, the ratio of the estimated cumulative release to the release limit for that radionuclide must be determined; ratios for all radionuclides are then summed for comparison to the requirements of § 191.13(a). Thus, the quantity of a radionuclide that may be released depends on the quantities of all other radionuclides projected to be released but cannot exceed its own release limit. The summed normalized release cannot exceed 1 for probabilities greater than 0.1, and cannot exceed 10 for probabilities greater than 0.001 but less than 0.1 (§ 191.13(a)). Potential releases estimated to have probabilities less than 0.001 are not limited (§ 191.13(a)). Calculation methods for summed normalized releases are described in more detail in Volume 2 of this report.

3.3.3 Human Intrusion

Determining compliance with the Standard requires performance assessments that include the probabilities and consequences of disruptive events. Appendix B of the Standard indicates that "inadvertent and intermittent intrusion by exploratory drilling for resources ... can be the most severe intrusion scenario assumed by the [DOE]" (US EPA, 1985, p. 38089).

In the Second Modification to the Consultation and Cooperation Agreement (US DOE and State of New Mexico, 1981, as modified), the DOE agreed to prohibit further subsurface mining, drilling, slant drilling under the withdrawal area, or resource exploration unrelated to the WIPP Project from the land surface to 6000 feet (1830 m) in the subsurface for the 16 square miles under DOE control. The Standard limits reliance on future institutional control in that "performance assessments... shall not consider any contributions from active institutional controls for more than 100 years after disposal" (§ 191.14(a)). The Standard further requires that "disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location" (§ 191.14(c)). The possibility of inadvertent human intrusion into repositories in salt formations during resource evaluation must be considered, and the use of passive institutional controls to deter such intrusion should be "taken into account" in performance assessments (US EPA, 1985, p. 38080).

The EPA gives specific guidance in Appendix B of the Standard for considering inadvertent human intrusion. The EPA indicates that only realistic possibilities for human intrusion that may be mitigated by design, site selection, and passive institutional controls need be considered. Additionally, the EPA assumes that passive institutional controls should "...reduce the chance of inadvertent intrusion compared to the likelihood if no markers and records were in place." Exploring for subsurface resources requires extensive and organized effort. Because of this effort, information from passive institutional controls is likely to reach resource explorers and deter intrusion into the disposal system (US EPA, 1985, p. 38080). In particular, as long as passive institutional controls "endure and are understood," the guidance states that they can be assumed to deter "systematic or persistent exploitation" of the disposal site, and furthermore, "can reduce the likelihood of inadvertent, intermittent human intrusion." The EPA indicates in Appendix B of the Standard that exploratory drilling for resources is the most severe intrusion that must be considered (US EPA, 1985, p. 38089). Because of the Standard's emphasis on exploratory drilling for resources as the most severe type of human intrusion to be considered at a disposal site, mining within the controlled area has not been included in performance assessment for the WIPP (Guzowski, 1990). Mining outside the WIPP boundary was retained for scenario development because of the possible effects on recharge and groundwater flow of subsidence over mined areas (Guzowski, 1990; Guzowski and Helton, 1991, Section 4.1.4). Consequences of such potash mining have not yet been included in performance-assessment modeling and will be addressed in future analyses when a three-dimensional model for regional groundwater flow is available.

Effects of site location, repository design, and passive institutional controls can be used in judging the likelihood and consequences of inadvertent drilling intrusion. The EPA suggests in Appendix B of the Standard that intruders will soon detect or be warned of the incompatibility of their activities with the disposal site by their own exploratory procedures or by passive institutional controls (US EPA, 1985, p. 38089).

Appendix B specifies that credit for using active institutional controls to prevent or reduce radionuclide releases cannot be taken for more than 100 years after decommissioning (US EPA, 1985, p. 38088). In previous performance assessments (Bertram-Howery et al., 1990; WIPP PA Division, 1991a), the WIPP Project has assumed that no human intrusion of the repository would occur during the 100-year period of active institutional controls, but that site-specific exploitation outside the controlled area might occur. For the 1992 performance assessment, the probabilities of human intrusion were also considered based on the judgments of an expert panel (see memorandum by Hora in Volume 3, Appendix A of this report). Comparisons of performance estimated using both the probabilities based on expert judgment and the probability model used in 1991 are provided in Chapter 5 of this volume.

Appendix B of the Standard (US EPA, 1985, p. 38089) specifies that after the period of active institutional control, the predicted number of exploratory boreholes assumed to be drilled inside the controlled area through inadvertent human intrusion is to be based on site-specific information and need not exceed 30 boreholes/km^2 (0.4 mi^2) per 10,000 years. No more severe scenarios for human intrusion inside the controlled area need be considered. Appendix B also indicates that while passive institutional controls endure, they can reduce the likelihood of inadvertent human intrusion to a degree to be determined by the DOE, although the possibility of inadvertent intrusion cannot be eliminated (US EPA, 1985, p. 38088).

Given the approach chosen by the EPA for defining the disposal standards, repository performance must be predicted probabilistically to evaluate compliance quantitatively. Determining the probability of intrusion poses questions that cannot be answered by numerical modeling or experimentation. Projecting future drilling activity requires unattainable knowledge about complex variables such as economic demand for natural resources, institutional control over the site, public awareness of radiation hazards, and changes in exploration technology. The 1992 preliminary performance assessment uses estimates of the probability of human intrusion that are based on guidance from expert panels on possible future societies and on the potential effectiveness and duration of passive institutional controls to deter intrusion into the WIPP (Hora et al., 1991; also see Volume 2 of this report and the memorandum by Hora in Volume 3, Appendix A of this report).

3.3.4 Uncertainties

The EPA recognizes in the preamble to the Standard that "standards must be implemented in the design phase for ... disposal systems because active surveillance cannot be relied upon" over the long time of interest. The EPA further notes that "standards must accommodate large uncertainties, including uncertainties in our current knowledge about disposal-system behavior and the inherent uncertainties regarding the distant future" (US EPA, 1985, p. 38070). Within the text of the Standard, the definition of performance assessment requires "considering the associated uncertainties" (§ 191.12(q); see Section 3.3.1 of this volume).

"Uncertainties in parameters" are the only source of uncertainty specifically identified in the Standard (US EPA, 1985, Appendix B, p. 38088). Uncertainty in input parameters used in predictive models may result from several sources, including incomplete data, intrinsic spatial variability of the property in question, measurement uncertainty, and uncertainty resulting from differences in scale between data acquisition and model application. Uncertainty in input parameters is not, however, the only potential source of uncertainty in performance assessment. As indicated in the following definitions adopted from Gallegos et al. (1992) and the NEA (1992a), additional uncertainty may enter the analysis through the choice of conceptual models used to represent the disposal system.

> Conceptual Model: A set of qualitative assumptions used to describe a system or subsystem for a given purpose. At a minimum, these assumptions concern the geometry and dimensionality of the system, initial and boundary conditions, time dependence, and the nature of the relevant physical and chemical processes. The assumptions should be consistent with one another and with existing information within the context of the given purpose.

> Alternative Conceptual Models: Alternative sets of assumptions that describe the same system for the same purpose, where each set of assumptions is consistent with the existing information.

> Conceptual Model Uncertainty: The lack of knowledge about the system resulting from limited information available to support or refute alternative conceptual models.

Uncertainty may exist also in the computational models used to perform quantitative analyses based on the chosen conceptual models. As used here, computational models include the mathematical models used to represent the physical processes, the numerical models used to solve the mathematical models, and the computer codes used to implement the solution.

The selection of scenarios to be analyzed also may introduce uncertainty into the estimated performance. Scenario uncertainty may be further subdivided into uncertainty in the completeness of the scenarios considered, uncertainty in the way in which computational results are aggregated to represent scenario consequences, and uncertainty in the probabilities associated with their occurrence.

Performance assessment thus requires considering numerous uncertainties in the projected performance of the disposal system. The WIPP Performance Assessment Department's methodology for uncertainty analysis (described in Chapter 4 of this volume and Volume 2, Chapters 3 and 4 of this report) relies on the selection of scenarios to be analyzed, the determination of scenario probabilities, and the calculation of scenario consequences using a Monte Carlo simulation technique (Pepping et al., 1983; Hunter et al., 1986; Cranwell et al., 1987, 1990; Campbell and Cranwell, 1988; Rechard, 1989; Helton, 1991). The Performance Assessment Department will assess and reduce uncertainty to the extent practicable using a variety of techniques (Table 3-1). For example, the WIPP Project uses uncertainty analyses to evaluate the amount of variability in the results of a model that can be attributed to uncertainty in the parameter input data.

Table 3-1. Techniques for Assessing or Reducing Uncertainty in the WIPP Performance Assessment

Type of Uncertainty	Technique for Assessing or Reducing Uncertainty	References to Performance Assessment Reports (also see references cited within these reports)
Scenarios (Completeness, Aggregation, and Probabilities)	Expert Judgment and Peer Review	Marietta et al., 1989; Bertram-Howery et al., 1990, Chapter 4; Guzowski, 1990; Tierney, 1990; Helton, 1991; Guzowski and Helton, 1991; Hora et al., 1991; memorandum by Hora in Volume 3, Appendix A of this report
	Quality Assurance	Rechard et al., 1992a, 1992b
Conceptual Models	Expert Judgment and Peer Review	Marietta et al., 1989; Bertram-Howery et al., 1990; WIPP PA Division, 1991b; Volume 2 of this report
	Sensitivity Analysis	Helton et al., 1991, 1992; Volume 4 of this report
	Uncertainty Analysis	Helton et al., 1991, 1992; Volume 4 of this report
	Quality Assurance	Rechard et al., 1992b
Computational Models	Expert Judgment and Peer Review	Marietta et al., 1989; Bertram-Howery et al., 1990; WIPP PA Division, 1991b; Volume 2 of this report
	Verification and Validation*	Marietta et al., 1989; Bertram-Howery et al., 1990; WIPP PA Division, 1991b; Volume 2 of this report
	Sensitivity Analysis	Helton et al., 1991, 1992; Volume 4 of this report
	Quality Assurance	Rechard et al., 1991

* to the extent possible

Table 3-1. Techniques for Assessing or Reducing Uncertainty in the WIPP Performance Assessment (continued)

Type of Uncertainty	Technique for Assessing or Reducing Uncertainty	References to Performance Assessment Reports (also see references cited within these reports)
Parameter Values and Variability	Expert Judgment and Peer Review	Rechard et al., 1990a, 1990b; WIPP PA Division, 1991c; Trauth et al., 1992; Volume 3 of this report
	Data-Collection Programs	Annual program plans for the WIPP
	Sampling Techniques	Helton, 1991
	Sensitivity Analysis	Helton et al., 1991, 1992; Volume 4 of this report
	Uncertainty Analysis	Helton et al., 1991, 1992; Volume 4 of this report
	Quality Assurance	Rechard et al., 1992a

Source: After Bertram-Howery and Hunter, 1989b

Sensitivity analyses identify the main contributors to the observed variation in the results. These techniques typically are applied iteratively. The first iteration can include rather general assumptions leading to preliminary results that help focus these techniques in subsequent iterations. In this manner, the resources required to implement the techniques in Table 3-1 can be directed at the areas of the WIPP performance assessment where the benefits of understanding uncertainty and reducing it (where possible) would be the greatest.

Modeling the behavior of a hydrogeologic system such as the WIPP disposal system necessarily will be uncertain because knowledge about its real behavior is uncertain. Many of the parameters used as inputs to a model of the system are obtained only by a data-collection process. Investigators knowledgeable about the data they collect make a finite number of observations, choosing what parameters to measure, how to measure them, where to measure them, and when to measure them. However, the collection process itself can introduce uncertainty through measurement error, the system's inherent randomness, and limited sampling of the variable physical, chemical, and biological properties of the system. In many aspects of data collection, the professional judgment of an analyst with expertise in the area of investigation often enters into the scientific process. For example, selection of methods to collect data, interpretation of data, development of conceptual models, and selection of model parameters all require professional analysis and judgment. The analyst's final data set is based on available data, use of the parameter in the computational model, behavior of analogous systems, and the analyst's own expert judgment.

The WIPP Project will use more formalized expert judgment for some parameters or models identified as being important to WIPP performance in cases where significant uncertainty exists in the available data and conceptual models and experimental or field data cannot be practicably obtained. In these instances, formal elicitations will provide probability distributions for model parameters. These distributions may be used to provide guidance to the Project until experimental or field data become available, or, in those cases where direct acquisition of data is impossible or unrealistic, the elicited distributions may form part of the basis for compliance evaluation. Expert panels may also be used to provide independent evaluation.

Formal elicitation offers a structured procedure for gathering opinions from a panel of professionals with the recognized training and experience to address a specific problem. The process encourages diversity in opinions and thus guards against understating uncertainty. In addition, formal elicitation promotes clear and thorough documentation of the manner in which results are achieved (Hora and Iman, 1989). The judgments that result from formal elicitation represent the current state of knowledge and provide a consensus of understanding, but they do not create information. An important aspect of elicitation, either during or following the process, is examining the manner in which new data may improve understanding. As new observations are made, the state of knowledge is refined. Thus far, expert panels have provided estimates of solubility and sorption parameters for selected radionuclides (Trauth et al., 1992). Additional expert panels may be convened to quantify other parameters and thus address the uncertainty in using those important data sets and associated conceptual models.

WIPP performance assessment must also address the potential for human intrusion and the effectiveness of passive institutional controls to deter such intrusion. An expert panel has already provided judgment on future societies' possible technical capabilities, needs, and social structures (Hora et al., 1991). An additional panel has developed marker characteristics to maximize both marker lifetimes and information that could be communicated to future generations. These panel judgments were used in the 1992 performance assessment and are discussed in Volumes 2 and 3 of this report. Another expert panel is under consideration to develop strategies for barriers to intrusion-by-drilling.

One type of uncertainty that cannot be completely resolved is the validity of various conceptual and computational models for predicting disposal-system behavior 10,000 years into the future. Although models will be validated using available site or analog data to the extent possible, expert judgment will be relied upon where validation is not possible. Uncertainties arising from the numerical solutions of a mathematical model are resolved in the process of verification (checking for numerical accuracy) of computer programs. Uncertainty resulting from the scenarios selected for modeling is most appropriately addressed in scenario development through a systematic and thorough examination of possible scenario components (events and processes); in scenario screening based on probability, consequence, physical reasonableness, and regulatory guidance; and in probability assignment by the techniques used for evaluation or estimation. Expert judgment to evaluate completeness and provide estimates of probabilities for events and processes may also be necessary (US DOE, 1990a).

Quality assurance (QA) procedures for performance assessment control analysis results in three areas—data, software, and analysis—and two subareas—elicitation of judgments from expert panels and documentation. QA procedures for data on facility design and geologic model parameters control traceability and documentation of data (Rechard et al., 1992a). QA procedures for software ensure that it performs as expected during the analysis by controlling traceability, retrievability, verification, and documentation (Rechard et al., 1991). QA procedures for analysis provide a framework and process so that analysis results present a reliable view of WIPP performance based on the present knowledge by controlling traceability, validation, personnel qualifications, data use, and peer review (Rechard et al., 1992b). QA procedures for documentation ensure that sufficient documented information is available to record how analyses were performed and how decisions were reached by specifying technical, management, and critical peer reviews (Rechard et al., 1992b).

3.3.5 Compliance Assessment

The Standard assumes that the results of the performance assessment for § 191.13(a) will be incorporated, to the extent practicable, into an overall probability distribution of cumulative release. In Appendix B of the Standard, the EPA assumes that, whenever practicable, results can be assembled into a single complementary cumulative distribution function (CCDF) that indicates the probability of exceeding various levels of summed normalized cumulative releases (US EPA, 1985, p. 38088) (Figure 3-3).

Descriptions of a procedure for performance assessment based on the construction of a CCDF are available (Pepping et al., 1983; Hunter et al., 1986; Cranwell et al., 1987, 1990; Campbell and Cranwell, 1988; Rechard, 1989; Helton, in press). The construction of CCDFs follows from the development of scenario probabilities and the calculation of scenario consequences. Further, the effects of different types of uncertainties can be shown by constructing families of CCDFs and then reducing each family to a single CCDF. The construction of families of CCDFs and various summary CCDFs is described in Volume 2 of this report.

Currently, CCDF curves for single scenarios and single conceptual models are used extensively in performance-assessment sensitivity analysis for comparing alternative conceptual models (Helton et al., 1991, 1992). Such CCDF curves do not establish compliance or noncompliance, but they convey vital information about how changes in model assumptions or parameter distributions may influence performance (Bertram-Howery and Swift, 1990).

Preliminary performance assessments are performed periodically for the WIPP to provide interim guidance to the Project as it prepares for final compliance evaluations. No "final" CCDF curves yet exist because the

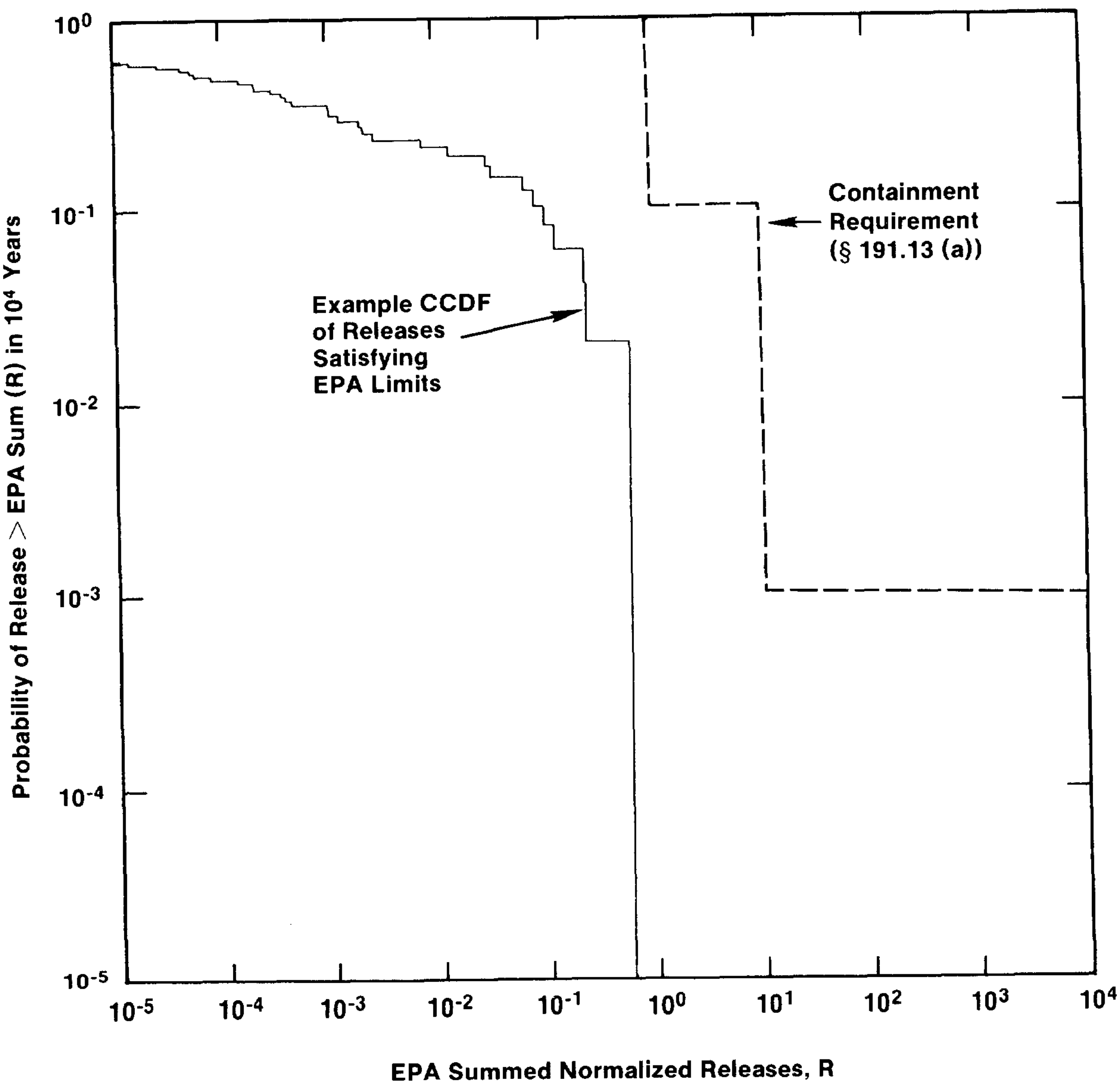


Figure 3-3. Hypothetical CCDF illustrating compliance with the Containment Requirements (after Marietta et al., 1989).

modeling system is incomplete and some input parameters have yet to be fully specified. Final probabilities for specific scenarios and many parameter-value distribution functions are still undetermined (see Volumes 2 and 3 of this report); therefore all CCDF curves presented in this report are preliminary. Although the compliance limits are routinely included on plots as reference points, the currently available curves should not be used to judge compliance with the Containment Requirements because the curves reflect an incomplete modeling system (Volume 2 of this report) and incomplete data (Volume 3 of this report) and because the Standard has not been repromulgated.

3.3.6 "Reasonable Expectation" of Compliance

The EPA assumes that a single CCDF will incorporate all uncertainty (US EPA, 1985, p. 38088). The Containment Requirements (§ 191.13(a)) state that, based upon performance assessment, releases shall have probabilities not exceeding specified limits. Appendix B of the Standard states that "the [EPA] assumes that a disposal system can be considered to be in compliance with § 191.13 if this single distribution function meets the requirements of § 191.13(a)" (US EPA, 1985, p. 38088). However, § 191.13(b) states:

> "Performance assessments need not provide complete assurance that the requirements of 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with 191.13(a) will be achieved."

Given the discussions on use of qualitative judgment in Appendix B to the Standard, the EPA means the entire record, including qualitative judgments. The guidance states:

> "The [EPA] believes that the implementing agencies must determine compliance with §§ 191.13, 191.15, and 191.16 of Subpart B by evaluating long-term predictions of disposal system performance. Determining compliance with § 191.13 will also involve predicting the likelihood of events and processes that may disturb the disposal system. In making these various predictions, it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgment relevant to the numerical predictions. Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical

> predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgments as well."

Thus, the EPA assumes that satisfying the numeric requirements is sufficient to demonstrate compliance with § 191.13(a) but not mandatory. A basis for concluding that a system provides good isolation can include qualitative judgment as well as quantitative results and thus does not totally depend upon the calculated CCDF. As discussed in the "Test Phase Plan" currently being prepared by the DOE, and in the ***Technical Needs Assessment*** report (US DOE, 1992a), the likelihood that excess releases will occur must be considered in the qualitative decision about a "reasonable expectation" of compliance but is not necessarily the deciding factor.

In the supplementary information published with the Standard, the EPA states that "the numerical standards chosen for Subpart B, by themselves, do not provide either an adequate context for environmental protection or a sufficient basis to foster public confidence..." (US EPA, 1985, p. 38079). The EPA also states that "factors such as [food chains, ways of life, and the size and geographical distributions of populations] cannot be usefully predicted over [10,000 years]....The results of these analyses should not be considered a reliable projection of the 'real' or absolute number of health effects resulting from compliance with the disposal standards" (US EPA, 1985, p. 38082).

The EPA recognizes that too many uncertainties exist in projecting the behavior of natural and engineered components for 10,000 years and that too many opportunities for errors in calculations or judgments are possible for the numerical requirements to be the sole basis for determining the acceptability of a disposal system (US EPA, 1985, p. 38079). Qualitative Assurance Requirements (discussed further in Section 3.4 of this volume) were included in the Standard to ensure that "cautious steps are taken to reduce the problems caused by these uncertainties." These qualitative Assurance Requirements are "an essential complement to the quantitative containment requirements" (US EPA, 1985, p. 38079). Each qualitative requirement was chosen to compensate for some aspect of the inherent uncertainty in projecting the future performance of a disposal system (see Section 3.4 of this volume). The Assurance Requirements begin by declaring that compliance with their provisions will "provide the confidence needed for long-term compliance with the requirements of 191.13" (§ 191.14).

Determining compliance with Subpart B depends on the estimated overall probability distribution of cumulative releases and on the estimated annual doses; however, it also depends on the strength of the assurance strategies (US DOE, 1987, currently in revision) that will be implemented and on the qualitative judgment of the DOE and its analysts. The preceding discussion demonstrates the EPA's recognition of the difficulties involved in predicting the future and in quantifying the outcomes of future events. The EPA expects the DOE to understand the uncertainties in the disposal system's behavior to the extent practical, while recognizing that substantial uncertainties will nevertheless remain.

3.4 Assurance Requirements

The EPA included Assurance Requirements (§ 191.14) in the 1985 Standard to provide confidence the agency believes is needed for long-term compliance with the Containment Requirements. These requirements apply only to disposal systems not regulated by the NRC, because comparable provisions exist in NRC regulations. The Assurance Requirements are designed to complement the Containment Requirements because of the uncertainties involved in predicting long-term performance of disposal systems (US EPA, 1985, p. 38072).

Each Assurance Requirement applies to some aspect of uncertainty about long-term containment:

Limiting reliance on active institutional controls to 100 years precludes relying on future generations to maintain surveillance;

Carefully planned monitoring will reduce the likelihood of unexpectedly poor system performance going undetected;

Using passive institutional controls such as markers and records will reduce the chances of inadvertent or systematic intrusion;

Including multiple barriers, both engineered and natural, will reduce the risk should one type of barrier not perform as expected;

Considering future resource potential and demonstrating that the favorable characteristics of the disposal site compensate for the likelihood of disturbance will add to the confidence that the chosen site is appropriate;

Selecting a disposal system that permits possible future recovery of most of the wastes for a reasonable period of time after disposal will allow future generations the option of relocating the wastes should new developments warrant such recovery (US DOE,

> 1990d). In promulgating the Standard, the EPA stated that "the intent of this provision was not to make recovery of waste easy or cheap, but merely possible...because the [EPA] believes that future generations should have options to correct any mistakes that this generation might unintentionally make" (US EPA, 1985, p. 38082). The EPA also stated that "*any* current concept for a mined geologic repository meets this requirement *without* any additional procedures or design features" (US EPA, 1985, p. 38082, emphasis in original).

3.5 Individual Protection Requirements

The Individual Protection Requirements (§ 191.15) of the Standard require predicting potential doses to humans resulting from releases to the accessible environment for undisturbed performance during the first 1000 years after decommissioning of the repository, in the event that performance assessments predict such releases. Although challenges to this requirement contributed to the remand of Subpart B to the EPA, the WIPP Project has made no assumptions about how the requirement may change when the Standard is repromulgated.

The methodology developed for assessing compliance with the Containment Requirements can be used to estimate doses as specified by the Individual Protection Requirements. One of the products of scenario development for the Containment Requirements is a base-case scenario for the WIPP that describes undisturbed conditions. The undisturbed performance of the repository is its design-basis behavior, including variations in that behavior resulting from uncertainties in the 10,000-year performance of natural and engineered barriers and excluding human intrusion and unlikely natural events, as defined in §191.12(p):

> "'Undisturbed performance' means predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events."

Undisturbed performance for the WIPP is understood to mean that uncertainties in such repository features as engineered barriers (seals and plugs) must be specifically included in the analysis of the predicted behavior (US DOE, 1990a). Human intrusion means any human activity other than those directly related to repository characterization, construction, operation, or monitoring. The effects of intrusion are specifically excluded from the undisturbed-performance analysis (US DOE, 1989).

Because of the relative stability of the natural systems within the region of the WIPP disposal system, all events and processes that are expected to occur naturally are part of the base-case scenario and are assumed to represent undisturbed performance (Marietta et al., 1989). Unlikely natural events not included in undisturbed performance of the WIPP are those events and processes that have not occurred in the past at a sufficient rate to affect the Salado Formation at the repository horizon within the controlled area and potentially cause the release of radionuclides.

The EPA assumes in Appendix B to the Standard that compliance with the Individual Protection Requirements "can be determined based upon best estimate predictions" rather than a probabilistic analysis. Thus, according to the EPA, when uncertainties are considered, only "the mean or median of the appropriate distribution, whichever is higher," need fall below the limits (US EPA, 1985, p. 38088).

The Individual Protection Requirements state that "the annual dose equivalent from the disposal system to any member of the public in the accessible environment" shall not exceed "25 millirems to the whole body or 75 millirems to any critical organ" (§ 191.15). These requirements apply to undisturbed performance of the disposal system, considering all potential release and dose pathways, for 1000 years after disposal. A specifically stated requirement is that modeled individuals be assumed to consume 2 L (0.5 gal) per day of drinking water from a significant source of groundwater, as defined in the Standard:

> "'Significant source of ground water'...means: (1) An aquifer that: (i) Is saturated with water having less than 10,000 milligrams per liter of total dissolved solids; (ii) is within 2,500 feet of the land surface; (iii) has a transmissivity greater than 200 gallons per day per foot, provided that any formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than 2 gallons per day per square foot...; and (iv) is capable of continuously yielding at least 10,000 gallons per day to a pumped or flowing well for a period of at least a year; or (2) an aquifer that provides the primary source of water for a community water system as of [November 18, 1985]" (§ 191.12(n)).

No water-bearing unit at the WIPP meets the first definition of significant source of groundwater at tested locations within the land-withdrawal area. At most well locations, water-bearing units meet neither requirement (i) nor (iii): total dissolved solids exceed 10,000 mg/L and transmissivity is less than 200 gallons per day per foot (26.8 $ft^3/ft \cdot day$ or 2.9×10^{-5} $m^3/m \cdot sec$) (Siegel et al., 1991; Brinster, 1991). Outside the land-withdrawal area, however, portions of the Culebra Dolomite Member do meet the requirements of the first definition. The WIPP Project will assume that any *portion* of an aquifer that meets the first definition is a significant source of groundwater and will examine communication between nonqualifying and qualifying portions. No community water system is being supplied by any aquifer near the WIPP; therefore, no aquifer meets the second definition of significant source of groundwater (US DOE, 1989).

Based on current evaluations, no units near the WIPP appear to meet the entire definition of a significant source of groundwater. The nearest aquifer that meets the first definition of a significant source of groundwater over its entire extent is the alluvial and valley-fill aquifer along the Pecos River. Communication between this aquifer and any other aquifers near the WIPP will be evaluated in future analyses when an improved model for regional groundwater flow is available (US DOE, 1989). Studies will include reviewing and assessing regional and WIPP drilling records and borehole histories for pertinent hydrologic information (US DOE, 1990a).

No releases from the undisturbed repository/shaft system are expected to occur within the 1000-year period of the Individual Protection Requirements, nor within the 10,000-year period of the Containment Requirements (Lappin et al., 1989; Marietta et al., 1989; WIPP PA Division, 1991b; WIPP PA Department, 1992; Chapter 5 of this volume). Therefore, dose predictions for undisturbed performance are not expected to be necessary. To date, analyses of undisturbed conditions indicate successful long-term isolation of the wastes (see Chapter 5 of this volume).

3.6 Groundwater Protection Requirements

Special sources of groundwater are protected by the Groundwater Protection Requirements (§ 191.16) from contamination at levels greater than certain limits. "Special sources of groundwater" are defined as

> "those Class I ground waters identified in accordance with the [EPA's] Ground-Water Protection Strategy published in August 1984 that: (1) Are within the controlled area encompassing a disposal system or are less than five kilometers beyond the controlled area; (2) are supplying drinking water for thousands of persons as of the date that the [DOE] chooses a location within that area for detailed characterization as a potential site for a disposal system (e.g., in accordance with Section 112(b)(1)(B) of the NWPA); and (3) are irreplaceable in that no reasonable alternative source of drinking water is available to that population" (§ 191.12(o)).

Class I groundwaters are defined as follows (US EPA, 1984):

> "Certain ground-water resources are in need of special protective measures. These resources are defined to include those that are highly vulnerable to contamination because of the hydrogeological characteristics of the areas under which they occur. Examples of hydrogeological characteristics that cause groundwater to be vulnerable to contamination are high hydraulic conductivity (karst formations, sand and gravel aquifers) or recharge conditions (high water table overlain by thin and highly permeable soils). In addition, special groundwaters are characterized by one of the following two factors:
>
> (1) Irreplaceable source of drinking water. These include groundwater located in areas where there is no practical alternative source of drinking water (islands, peninsulas, isolated aquifers over bed rock) or an insufficient alternative source for a substantial population; or
>
> (2) Ecologically vital, in that the groundwater contributes to maintaining either the base flow or water level for a particularly sensitive ecological system that, if polluted, would destroy a unique habitat (e.g., those associated with wetlands that are habitats for unique species of flora and fauna or endangered species)."

As defined in the Groundwater Protection Requirements, no special sources of groundwater exist at the WIPP within the maximum area allowed (Figure 3-4); therefore, the requirement to estimate radionuclide concentrations in such groundwater is not relevant to the WIPP (see Chapter 5 of this volume).

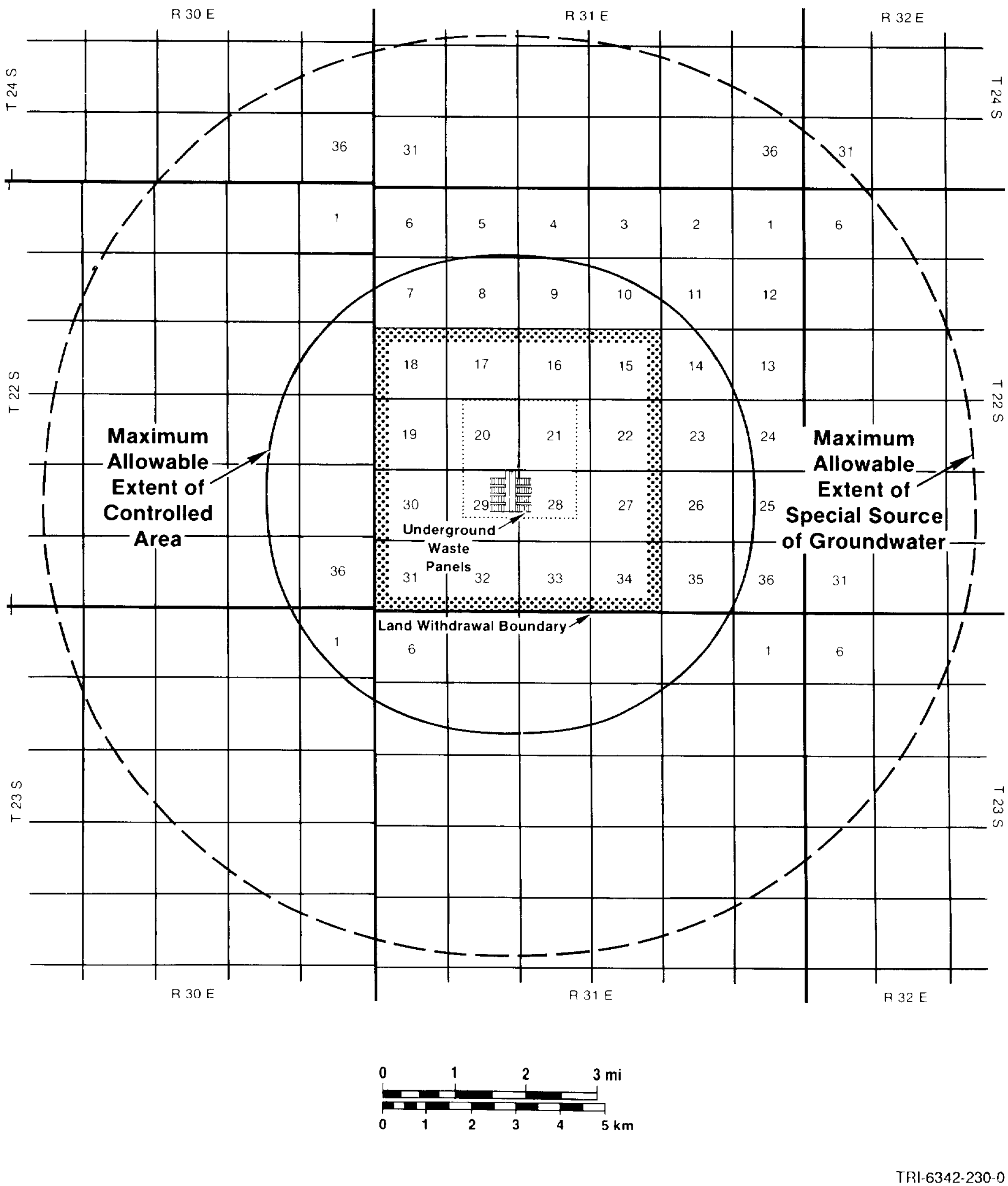


Figure 3-4. Illustration of boundary definitions pertaining to the Groundwater Protection Requirements (after US DOE, 1989). The dashed line, drawn 5 km (3 mi) from the maximum allowable extent of the controlled area (§ 191.12(g)), shows the maximum area in which the occurrence of a special source of groundwater (§ 191.12(o)) is of regulatory interest.

4. PERFORMANCE-ASSESSMENT METHODOLOGY

This chapter contains a brief and simplified overview of the methodology used in WIPP performance assessment. A more complete discussion is presented in Volume 2 of this report and in references cited therein.

The WIPP performance assessment represents risk as a triplet consisting of the answers to the following three questions (Kaplan and Garrick, 1981):

(1) What can happen? (scenarios)

(2) How likely are things to happen? (probabilities of scenarios)

(3) What are the consequences of these things (scenarios) happening?

The first question is answered by a systematic scenario construction procedure that results in a set of comprehensive and mutually exclusive scenarios for consequence analysis (Guzowski, 1990; Cranwell et al., 1990; NEA, 1992b). Answering the second question requires that probability estimates be made for the scenarios retained for analysis. A formal elicitation procedure using expert panels has been recommended by other programs (Hora and Iman, 1989; Andersson et al., 1989; Stephens and Goodwin, 1989; Bonano et al., 1990) and employed by WIPP performance assessment. Answering the third question requires a modeling system to estimate consequences, expressed in terms of the performance measures of interest. The WIPP performance assessment uses a Monte Carlo technique to examine uncertainty in performance estimates and to perform sensitivity analyses that provide guidance to the Project.

The WIPP performance assessment is iterative, and answers to each of these three questions will be reexamined as the Project moves toward a final regulatory compliance evaluation. Thus, the set of scenarios selected for consequence analysis may change as new information dictates (although the scenarios examined in 1992 are essentially unchanged from 1991). Scenario probabilities have changed as expert judgment is incorporated, and the modeling system continues to change as new models and data become available.

4.1 Scenarios

WIPP performance assessment uses a formal scenario-selection procedure consisting of five steps (Cranwell et al., 1990): (1) compiling or adopting a comprehensive set of events and processes that potentially could affect the disposal system, (2) classifying the events and processes to aid in completeness arguments, (3) screening the events and processes to identify those that can be eliminated from consideration in the performance assessment, (4) developing scenarios by combining events and processes that remain after screening, and (5) screening scenarios to identify those that have little or no effect on the performance estimate. In the application of this scenario-selection process to the WIPP, events and processes were screened according to probability, consequence, and physical reasonableness. Following guidance from the Containment Requirements of the Standard (§ 191.13), those events and processes with a probability of less than 10^{-4} in 10,000 years were eliminated, as were those which would have little or no consequence on performance or which would be physically unreasonable. This screening process is summarized in Volume 2, Chapter 4 of this report, and is described in detail in the 1991 documentation (Guzowski and Helton, 1991).

For the WIPP, the result of the scenario-selection process is a set of eight scenarios constructed from three retained events (Figure 4-1). No scenarios resulting from the selection process have been screened out. Scenarios shown in Figure 4-1 that include the effects of subsidence due to potash mining have not been included in the 1992 or previous performance assessments, but the impact of subsidence events will be examined in future analyses. The four scenarios analyzed in 1992 are discussed in the following sections.

4.1.1 Undisturbed Performance (Base Case)

As defined in the Standard (§ 191.12(p)) and discussed in Section 3.5 of this volume, "'undisturbed performance' means the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events." The Standard does not define "unlikely," but the WIPP Performance Assessment Department interprets the probability cutoff of 10^{-4} in 10,000 years proposed in Appendix B of the Standard for the Containment Requirements (§ 191.13) to be a suitable working definition for the term.

No disruptive natural events with probabilities greater than 10^{-4} in 10,000 years were identified during the scenario-selection procedure, so "undisturbed performance" is the same as the "base case" scenario in Figure 4-1. Because of the relative stability of the natural systems within the region of the WIPP disposal system, all naturally occurring events and processes retained for scenario construction (e.g., climate variability) (1) will occur, (2) are part of the base-case scenario, and (3) are nondisruptive. The base-case scenario (Figure 4-2a) describes the disposal

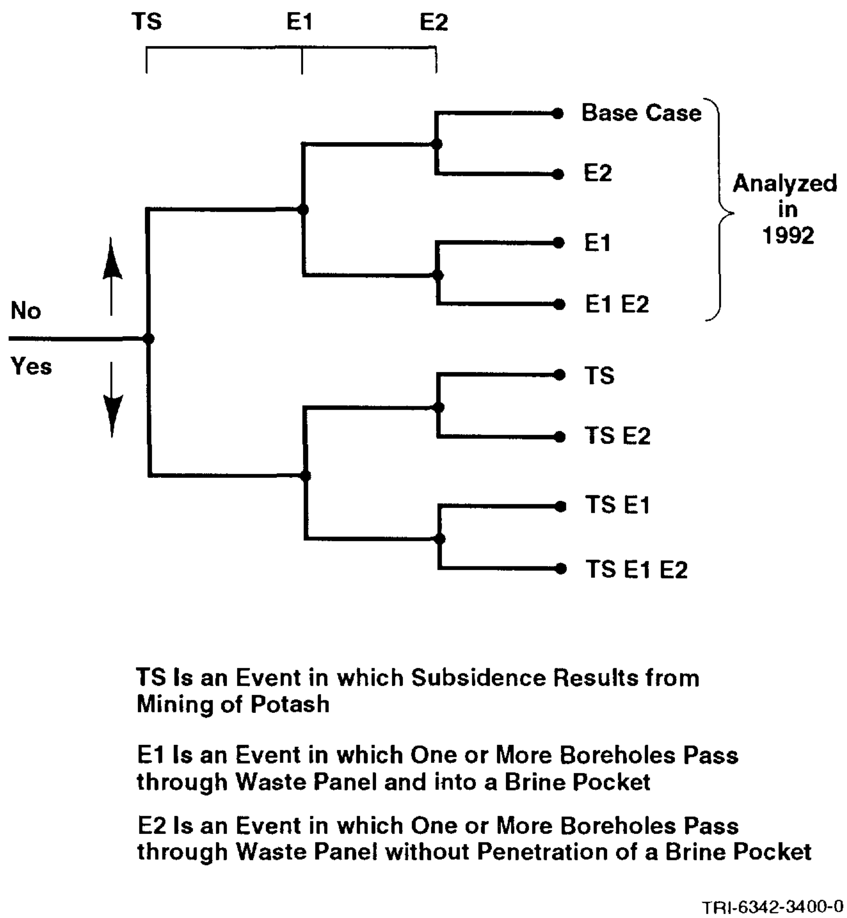


Figure 4-1. Potential scenarios for the WIPP disposal system. Each scenario is a set of similar occurrences and a subset of all possible 10,000-year histories beginning at decommissioning of the WIPP.

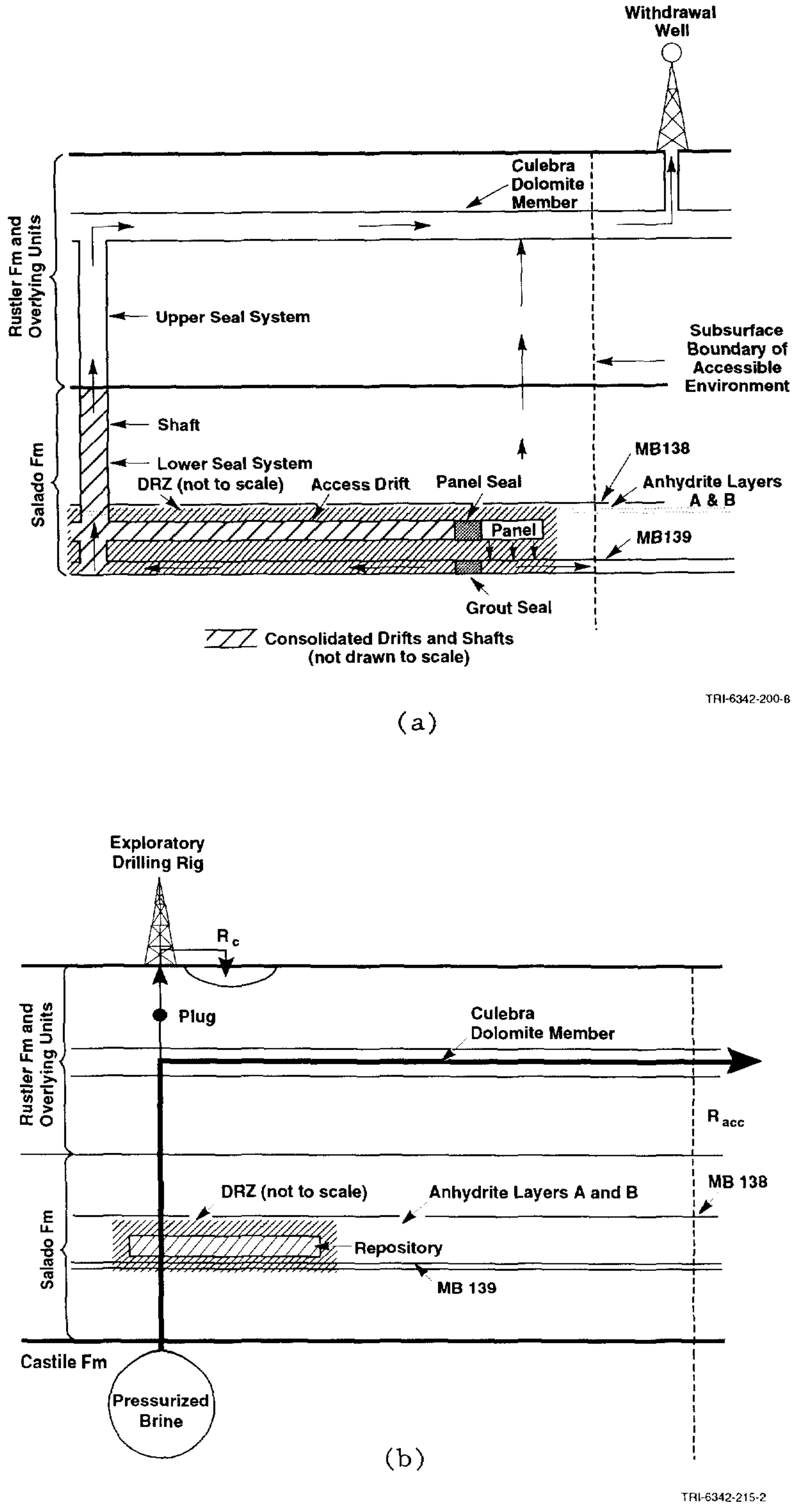


Figure 4-2. Conceptual models for (a) the undisturbed performance scenario and (b) the E1 scenario. Arrows indicate assumed direction and relative magnitude of flow. R_c is the release of cuttings and eroded material. R_{acc} is the release at the subsurface boundary of the accessible environment. Illustrated plugs are assumed to remain intact for 10,000 years.

system from the time of decommissioning and incorporates all expected changes in the system and associated uncertainties for the 10,000 years of concern for the Containment Requirements (§ 191.13). Two potential pathways for migration of radionuclides dissolved in brine are considered. In the first path, brine may migrate either through drifts or through the disturbed rock zone (DRZ) surrounding the excavation and anhydrite interbeds (primarily MB139) to the shafts and then upward toward the Culebra Dolomite Member of the Rustler Formation, which is the most permeable water-saturated unit overlying the repository. Transport may then occur laterally in the Culebra toward the subsurface boundary of the accessible environment. In the second path, brine may migrate laterally toward the subsurface boundary of the accessible environment within anhydrite interbeds in the Salado Formation. Considered for only 1000 years, and with the addition of a water withdrawal well to provide a potential pathway for radionuclides to reach humans, the base-case scenario is also suitable for evaluations of undisturbed performance for the Individual Protection Requirements (§ 191.15). Considering gas migration pathways to the disposal-unit boundary and, if necessary, transport of hazardous constituents in both gas and brine phases, the base-case scenario is suitable for evaluations of undisturbed performance for 40 CFR 268.6 (RCRA) (see Volume 5 of this report).

4.1.2 Inadvertent Human Intrusion

Performance assessments for 40 CFR 191, Subpart B, presently concentrate on inadvertent human intrusion during exploratory drilling for resources, which has been demonstrated by past analyses (Marietta et al., 1989; Bertram-Howery et al., 1990; WIPP PA Division, 1991a,b,c; WIPP PA Department, 1992; see also Section 5.2 of this volume) to be the only event likely to lead to radionuclide releases close to or in excess of regulatory limits. Future drilling technology is assumed for these analyses to be comparable to technology presently in use in the region around the WIPP.

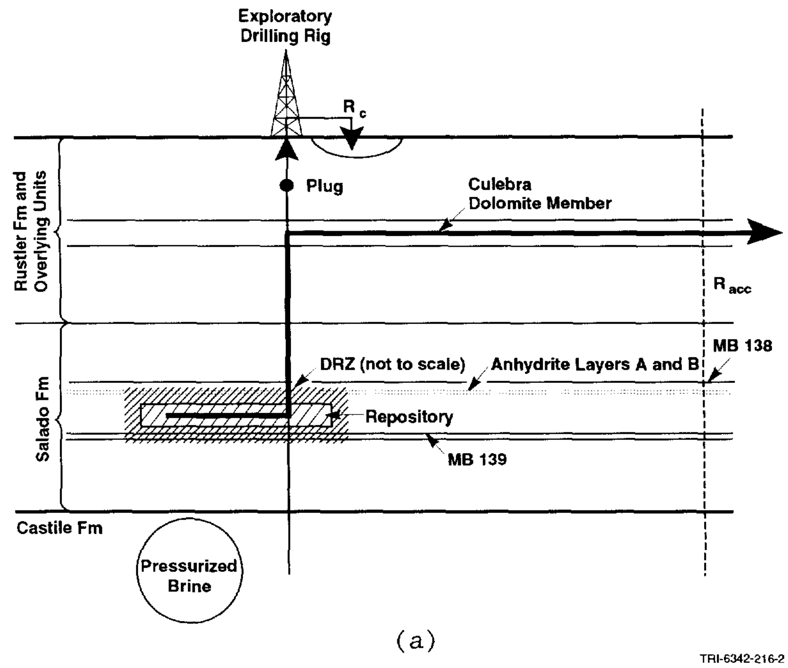
If the waste-emplacement panels are penetrated by an exploratory borehole, radionuclides may reach the accessible environment by two principal pathways. First, some radionuclides will be transported up the borehole directly to the ground surface. Second, additional radionuclides transported up the borehole will migrate into overlying strata and may be transported laterally in groundwater to the subsurface boundary of the accessible environment.

Most releases at the ground surface will be in the form of particulate waste entrained in the drilling fluid, including components from cuttings (material removed by the drill bit), cavings (material eroded from the borehole wall by the circulating drilling fluid), and spallings (material that enters the borehole as the repository depressurizes). For convenience, these particulate releases are collectively referred to in performance-assessment documentation as cuttings. For the 1992 calculations, results referred to as cuttings include cavings but do not include spallings. If important, spallings will be included in future performance assessments when models and data are available. Additional discussion of the modeling of particulate releases at the ground surface during drilling is provided in Volume 2, Section 7.7 of this report. Release of radionuclides dissolved in brine that may flow up the borehole to the ground surface both during drilling and after degradation of plugs has not been included either in past performance assessments or in the results presented in this volume. Volume 4 of the 1992 documentation will contain preliminary analyses of the potential for releases by this mechanism.

Subsurface releases of radionuclides following lateral transport in groundwater are believed to be most likely to occur in the Culebra Dolomite Member of the Rustler Formation overlying the repository. For analysis purposes, subsurface transport is assumed to occur only in the Culebra, maximizing the potential for releases by this pathway. Additional discussion of flow and transport in the Culebra is provided in Volume 2, Section 7.6 of this report.

Figures 4-2b and 4-3 illustrate the three representative intrusion scenarios shown in Figure 4-1. In the E1 scenario (Figure 4-2b), a borehole penetrates the repository and a hypothetical pressurized brine reservoir in the underlying Castile Formation. In the E2 scenario (Figure 4-3a), a borehole penetrates the repository and misses the hypothetical brine reservoir. In the E1E2 scenario (Figure 4-3b), one borehole penetrates the repository and the hypothetical brine reservoir and a second borehole penetrates the repository but misses the pressurized brine reservoir.

In all three of these intrusion scenarios, borehole plugs are assumed to be emplaced and to perform so as to maximize fluid flow into the Culebra Dolomite Member of the Rustler Formation. These plug configurations have been chosen to facilitate examination of the specific scenarios, and do not reflect the most realistic conditions expected. In the E1 and E2 scenarios, any plugs between the repository and the Culebra are assumed to fail immediately, whereas plugs above the Culebra remain effective for 10,000 years. In the E1E2 scenario, a plug in the E1-type borehole between the repository and the Culebra remains effective and forces flow through the waste and up the E2-type hole, where a plug above the Culebra forces flow laterally toward the accessible-environment boundary. As noted above,



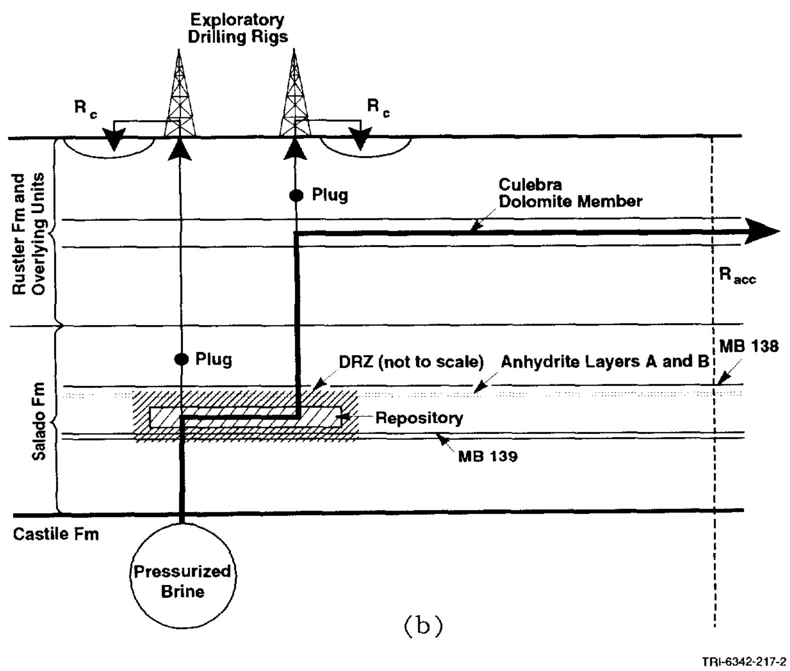


Figure 4-3. Conceptual models for (a) the E2 scenario and (b) the E1E2 scenario. Arrows indicate assumed direction and relative magnitude of flow. R_c is the release of cuttings and eroded material. R_{acc} is the release at the subsurface boundary of the accessible environment. Illustrated plugs are assumed to remain intact for 10,000 years.

consequences of alternative assumptions about plugging in which all plugs degrade to a material with relatively high permeability (as suggested in Appendix B of the Standard [US EPA, 1985, p. 38089]) and brine is allowed to flow at the ground surface will be examined and documented in a subsequent volume.

For improved computational resolution, the E1, E2, and E1E2 scenarios have been subdivided further into computational scenarios on the basis of time of intrusion and activity of the waste intersected. As discussed in Volume 2, Chapter 4 of this report, subsurface radionuclide releases following groundwater transport in the Culebra are calculated in the 1992 performance assessment only for intrusions occurring 1000 years after decommissioning. Because of the decreased time available for transport, later intrusions are expected to result in smaller releases. As in 1991, for computational efficiency, E1-type intrusions are not analyzed explicitly, but rather are assumed to have the same consequences as E2-type intrusions (WIPP PA Division, 1991b). Releases of cuttings are calculated for six time intervals, including intrusions at 125, 175, 350, 1000, 3000, and 7250 years. Multiple intrusions are allowed, with a maximum number of 10 occurring in simulations used in the 1992 analyses.

4.2 Probabilities of Scenarios

Identifying the probability of future human intrusion is at best a qualitative task. Preliminary performance assessments for the WIPP prior to 1990 considered a fixed number of human intrusions with fixed and arbitrary probabilities (Marietta et al., 1989; Guzowski, 1991). The 1990 preliminary assessment (Bertram-Howery et al., 1990) compared performance assuming fixed probabilities for intrusion events with performance estimated assuming that intrusion through the repository follows a Poisson process (i.e., intrusion events are random in time and space) with a rate constant, λ. The 1991 assessment (WIPP PA Division, 1991a,b) included a probability model based on the Poisson assumption and also included effects of variable activity loading with boreholes intersecting waste of five different levels of radioactivity (Helton et al., 1992). Based on guidance in Appendix B of the Standard, a maximum of 30 boreholes/km^2 were allowed in 10,000 years, although the largest number to occur in any realization was 10 per 0.5 km^2.

The 1992 preliminary performance assessment marks the first use for the WIPP of external expert judgment to estimate the probability of future intrusion. Teams of experts from outside the WIPP Project were selected and organized into two panels to address (1) the nature of future societies and the possible modes of intrusion, and (2) types of markers and their potential effectiveness in deterring intrusion (Hora et al., 1991; memorandum by Hora in Volume 3, Appendix A of this report). The judgments elicited from these panels were used to construct an algorithm describing possible changes in the Poisson rate constant, λ, with time (memorandum by Hora in Volume 3, Appendix A of this report). The 1992 preliminary performance assessment presents results calculated both using the 1991 time-invariant formulation for λ and the time-dependent formulation based on external expert judgment. Both formulations used the same representation for variable activity loading used in the 1991 performance assessment (Helton et al., 1992). The time-dependent formulation including the deterrence effect of markers resulted in significantly fewer intrusions (a maximum of 3 for intrusions occurring at 1000 years and 4 for the 6 intrusion times) than the time-invariant formulation (a maximum of 8 for intrusions occurring at 1000 years and 10 for 6 intrusion times).

4.3 Scenario Consequence Modeling

Consequence modeling for WIPP performance assessment uses a linked system of computational models to describe the disposal system and a Monte Carlo technique that relies on multiple simulations using sampled values for selected input parameters to quantify uncertainty in the performance estimate. A full analysis includes selecting imprecisely known parameters to be sampled, constructing distributions for each of these parameters incorporating available data and subjective information, generating a sample from these variables, and calculating consequences for each sample element. Consideration of alternative conceptual models (defined in Section 3.3.4 of this volume), which may require different input parameters and perhaps different computational models, at present is included by repeating the full analysis for each conceptual model to assess uncertainty among alternative models. Results for preliminary comparison with 40 CFR 191, Subpart B, are usually displayed in terms of complementary cumulative distribution functions (CCDFs), which are plots of exceedance probability versus consequence. The consequence measure for § 191.13 is the EPA normalized sum, as discussed in Section 3.3.2 of this volume and in Volume 3, Section 3.3.4 of this report. Construction of CCDFs is discussed in Volume 2, Chapter 3 of this report.

Uncertainty and sensitivity analyses use a Latin hypercube sampling technique followed by stepwise rank regression analysis (Iman and Helton, 1985; Helton et al., 1991, 1992). In other sensitivity analyses for alternative conceptual models, specific parameter groups are assigned fixed values corresponding to extreme and median values, and all other parameters in the data base are sampled probabilistically over the full range of possible values. A parameter or group of parameters is thus tested *ceteris* *paribus* (all other things being equal) within a Monte Carlo simulation (Helton et al., 1991). To compare with the Standard for each conceptual model, results are assembled into CCDF plots of probability versus 10,000-year normalized cumulative radionuclide release, as recommended in the guidance to the Standard. The technique isolates effects of variations in parameter groups (used to represent alternative conceptual models) on predicted performance. Priorities can then be suggested for future modeling and experimental research.

4.3.1 Computational Models

Major computer programs (codes) used in the computational models for the 1992 preliminary performance assessment (Figure 4-4) are described in detail in Volume 2 of this report. They reflect improvements in the conceptual and numerical models used in the 1991 and previous performance assessments, and permit the replacement of simplifying assumptions with more realistic models. Three of the most significant improvements in 1992 are discussed here.

The 1992 calculations mark the first time the effects of salt creep have been explicitly included in performance assessments. Salt will deform over time by creep in response to a pressure gradient, and, if the repository remained at atmospheric pressure, lithostatic stresses would cause it to close almost completely within 100 years (Tyler et al., 1988; Munson et al., 1989a,b). Gas will be generated within the repository by degradation of the waste, however, and pressure within the repository will rise to elevated levels that will retard complete creep closure and may perhaps partially reverse the process. In 1991, no model was available to describe the coupled interaction of creep closure and gas pressurization, and the performance-assessment calculations used a simplifying assumption that porosity within the disposal region would remain constant through time. As discussed in detail in Volume 2, Section 7.3 of this report, the 1992 calculations use output from the geomechanical code SANCHO (Stone et al., 1985) to define the porosity of the waste as a function of pressure. Although this method does not represent a full coupling of creep closure and gas generation, the modeling improvement allows the performance assessment to evaluate the importance of changing void volume in the repository. An analysis of the impact on performance of including salt creep is included in Volume 4 of this report.

The method used to incorporate spatial variability in the transmissivity field in the Culebra has been modified significantly from that used in 1991. The Performance Assessment Department now uses an automated inverse approach to calibrate a two-dimensional model to both

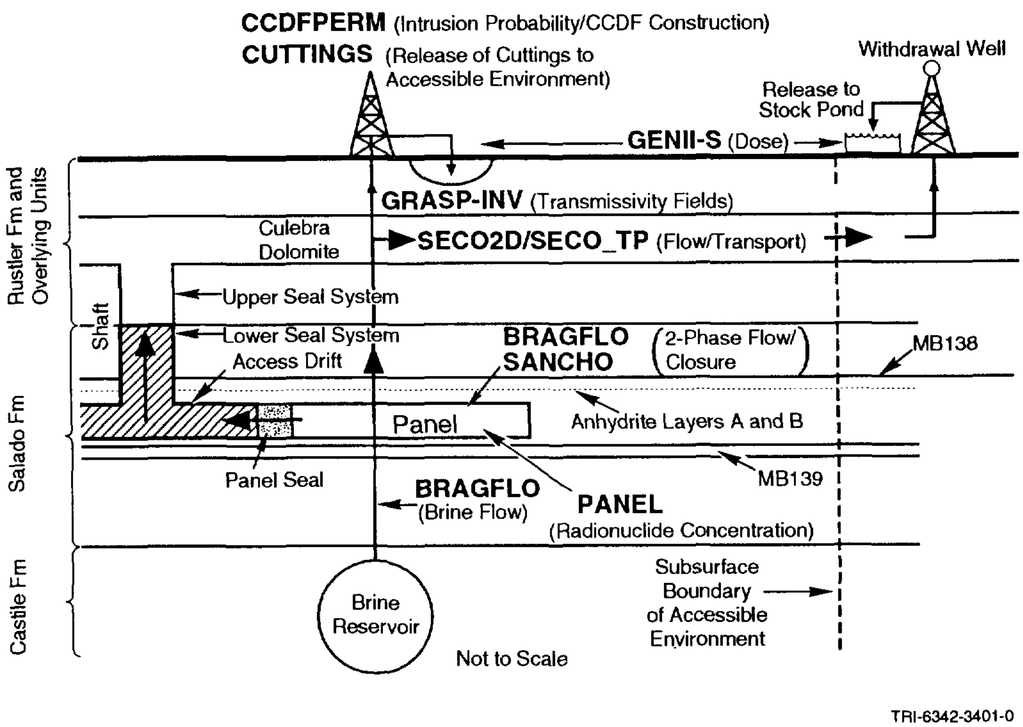


Figure 4-4. Major codes used in the 1992 performance assessment.

steady-state and transient pressure data generating multiple realizations of the transmissivity field (Volume 2, Section 7.5 of this report; LaVenue and RamaRao, 1992). Seventy calibrated fields were sampled for use in the 1992 performance assessment.

Radionuclide transport in the Culebra, which had been simulated using STAFF2D (Huyakorn et al., 1991) in the 1991 performance assessment, is now simulated by the SECO-TP code (Volume 3, Section 1.4.6 of this report). SECO-TP is a dual-porosity model in which advective transport is allowed only in fractures, and diffusion of solute occurs into the rock matrix surrounding the fracture. The fracture system is idealized as planar and parallel, and each fracture wall may be coated with a layer of clay of uniform thickness and porosity. The model is capable of simulating both physical retardation by diffusion and chemical retardation by sorption in both clay fracture-linings and dolomite matrix.

Several significant improvements remain to be made in the performance-assessment modeling system. Specifically, the model used in 1992 for groundwater flow in the Culebra does not include possible effects of subsidence related to potash mining or a representation of recharge that includes present or future vertical groundwater flow within the Rustler Formation (leakage). The model used to represent the response of the repository and the surrounding strata to the generation of gas by waste degradation does not include effects of possible pressure-dependent fracturing of anhydrite layers within the Salado Formation. Modeling system improvements also remain to be made with respect to gas generation, the conceptual three-dimensional model for regional groundwater flow, the impact of spallings and direct flow of brine up a borehole to the surface, transport of radionuclides as colloids, and possible correlations between input parameters used in computational models. Consequences of these aspects of disposal-system performance will be examined in future analyses as additional information becomes available.

4.3.2 Distributions for Imprecisely Known Variables

The complete data base used in the 1992 preliminary performance assessment is presented in Volume 3 of this report, and includes ranges and cumulative distribution functions (cdfs) for all sampled parameters and median values for all non-sampled parameters. Ranges for parameter values have been selected by WIPP Project researchers in their respective fields. The selection of parameters to be sampled is based on previous sensitivity analyses and, to some extent, on subjective judgment by the researchers on the importance of the parameters. Distribution functions for parameters have been assigned by the Performance Assessment Department using available data and the maximum entropy formalism (MEF), which minimizes the amount of spurious information that enters into cdf construction from sparse data or limited quantitative information (Tierney, 1990). For WIPP performance assessment, the MEF serves as a consistent mathematical procedure for deriving cdfs for imprecisely known variables from a set of quantitative constraints on the form of the distribution (e.g., range, mean, variance, or different percentiles). Two empirical distributions are particularly important. When measured data are available, the empirical cdf is piecewise uniform. Following the MEF, the empirical cdf is modified by joining the empirical percentile points (including extrapolated end points) with straight lines, resulting in a piecewise linear cdf. When data are not available and subjective point estimates are supplied by experts, the cdf is again piecewise linear and constructed by linearly connecting the subjective point estimates. Judgments that are made by experts are a snapshot of the current state of knowledge. As new observations are made for important parameters, this state of knowledge and the cdf are refined.

To supplement the available information for constructing the required cdfs, several expert panels were convened and a formal elicitation process was used (Bonano et al., 1990; Hora and Iman, 1989). A formal elicitation of expert opinion includes five components: selection of issue and issue statement, selection of experts, elicitation sessions, recomposition of an expert's opinion and aggregation of group opinion, and documentation. As did the 1991 performance assessment, the 1992 analyses include the outcomes of formal elicitations from two expert panels on important geochemical parameters. A source-term panel provided subjective point estimates for constructing logarithmic piecewise linear cdfs of radionuclide solubilities in disposal-room brine, and a second panel on radionuclide retardation in the Culebra provided estimates for distribution coefficients (Trauth et al., 1992). Members of the source-term panel concluded they could not make judgments about suspended-solids concentrations because of a lack of experimental data and consequently limited knowledge on colloids and their formation. The retardation panel estimated distribution coefficients (K_ds) for fracture clays and matrix dolomite using available data. Experimental programs have been initiated that will provide WIPP-specific data on both the source term (dissolved species and colloids) and retardation in the Culebra (US DOE 1992a,b).

The 1992 WIPP performance assessment selected 49 imprecisely known variables (including, for example, uncertain material properties of the waste, the Salado Formation, and the Culebra Dolomite) for consideration in the human-intrusion scenarios (Volume 3, Tables 6.0-1, 6.0-2, and 6.0-3 of this report). Values sampled from the distributions assigned to these 49 variables were used to construct 70 vectors of sampled parameters to use in Monte Carlo simulations. Sampled values for each of the 70 vectors are presented in Volume 4 of this report. Because 2 different scenarios were analyzed explicitly (E2 and E1E2), performance estimates reported for each conceptual model considered are based on 140 realizations of the full modeling system.

4.3.3 Generation of the Sample Elements

WIPP performance assessment uses a stratified sampling technique called Latin hypercube sampling (LHS) that ensures full coverage of the range of each sampled variable (McKay et al., 1979). The range of each variable is divided into N intervals of equal probability, and one value is randomly selected from each interval. The N values of the first parameter are randomly paired with the N values of the second parameter, and so on, until N sample elements (vectors) are obtained. This procedure ensures that the distribution tails are sampled and is a more efficient technique than simple random sampling in that fewer sample elements are required for a Monte Carlo analysis. The size of N (70 for the 1992 performance assessment) is selected based on the observation that a sample size of 4/3 times the number of sampled parameters is generally sufficient to capture variability in independent input parameters (Iman and Helton, 1985).

Most of the uncertain variables that were sampled during the 1992 performance assessment were assumed to be independent, although some are expected to be correlated in some way. For example, local porosity is probably correlated with local permeability in most media, but the correlation structure is unknown. Controlling correlation within a sample for Monte Carlo analysis is important to ensure that uncertainty and sensitivity analysis results are meaningful. WIPP performance assessment uses a rank correlation (i.e., on rank-transformed variables instead of on the original raw data) technique that effectively captures variable linkage while maintaining the integrity of the LHS intervals (Iman and Conover, 1982; Helton et al., 1991). However, the correlation structure for most of the uncertain variables that are expected to be correlated has not yet been adequately addressed. Future performance assessments will test approaches for dealing with these unknown correlations.

5. RESULTS OF THE 1992 PRELIMINARY COMPARISON WITH 40 CFR 191, SUBPART B

Results from the 1992 preliminary performance assessment are presented for informal comparison with the Containment Requirements and the Individual Protection Requirements of the Standard. Although not based on the 1992 preliminary performance assessment, the status of preliminary compliance with the Assurance Requirements and the Groundwater Protection Requirements is also discussed.

5.1 Containment Requirements

Compliance with the Containment Requirements is evaluated using CCDF curves that graph exceedance probability versus cumulative radionuclide releases for all significant scenarios. Results presented here are not suitable for final compliance evaluations because portions of the modeling system and data base are incomplete, conceptual-model uncertainties are not included, final scenario probabilities remain to be determined, the level of confidence in the results remains to be established, and the final version of the Standard has not been promulgated. Uncertainty analyses required to establish the level of confidence in results will be included in future performance assessments as advances permit quantification of uncertainties in the modeling system and the data base.

5.1.1 Previous Studies

Preliminary comparisons of the estimated performance of the WIPP with the Containment Requirements have been published iteratively since 1989 (Marietta et al., 1989; Bertram-Howery et al., 1990; WIPP PA Division 1991a). Annual sensitivity analyses have helped identify areas where improvements in the modeling system can increase overall confidence in the performance estimate (Helton et al., 1991, 1992), and each subsequent iteration of performance assessment has represented a significant advance over the preceding iteration.

The 1991 preliminary comparison indicated that, for the conceptual and computational models, parameter values, and scenario probabilities believed by the WIPP PA Department at that time to best represent the behavior of the disposal system, the mean CCDF lay an order of magnitude or more below the EPA compliance limits (WIPP PA Division, 1991a). As is also true for the 1992 preliminary comparison, the 1991 performance estimate could not be considered defensible for a final compliance evaluation. Results of uncertainty and sensitivity analyses conducted as part of the 1991 performance assessment have, however, provided valuable guidance to the Project as it moves toward a final compliance evaluation.

5.1.2 1992 Preliminary Comparison

The 1992 performance assessment has concentrated resources on analyzing the impact of specific sources of uncertainty on the performance estimate. Fewer times of intrusion have been considered (to allow allocating resources to simulation of alternative conceptual models), and the 1992 results are therefore less suitable in that sense for direct comparison to the EPA limits than were the 1991 results. In all other ways, however, the 1992 performance assessment reflects a more realistic representation of the future behavior of the disposal system. As described in Chapter 4 of this volume and Volume 2 of this report, major modeling improvements have been made in coupling creep closure of the repository to gas pressurization, in accounting for spatial variability of transmissivity in the Culebra Dolomite Member of the Rustler Formation, and in simulating radionuclide transport in the Culebra. As described in Volumes 2 and 3 of this report, other improvements have been made throughout the modeling system and the data base. As described in Chapter 4 of this volume, improvements remain to be made in many areas, including modeling of possible pressure-dependent fracturing of anhydrite interbeds in the Salado Formation, modeling of three-dimensional groundwater flow in the Rustler Formation, modeling of gas-generation processes, and acquisition of experimental data for actinide solubilities and retardations.

The 1992 preliminary comparison examines uncertainty resulting from imprecisely known values for input parameters and the impact of two additional sources of uncertainty: the probability of human intrusion, and the choice of conceptual model for transport in the Culebra. Past preliminary comparisons have shown that the location of the mean CCDF is sensitive to assumptions made about both sources (Bertram-Howery et al., 1990; Helton et al., 1992). Because the emphasis here is on the relative position of the CCDFs calculated with each set of assumptions, all figures shown here are comparisons of two or more CCDFs calculated using either different probabilities or alternative conceptual models (see Section 3.3.4 of this volume for definitions of conceptual model and alternative conceptual models). For simplicity, only mean curves are shown. The complete families of CCDFs (with a single curve for each of the 70 vectors) will be shown in an appendix of Volume 4 of this report for each case considered, together with summary plots showing the mean, median, 10th percentile, and 90th percentile curves. Analyses of uncertainty resulting from imprecisely known values for input parameters are provided in Volume 4 of this report.

5.1.2.1 CASES CONSIDERED FOR ANALYSIS IN 1992

Cases considered for analysis were defined on the basis of the choice of probability model for human intrusion (fixed rate constant versus time-dependent rate constant based on expert-panel judgment), the mode of release (cuttings versus subsurface transport), and the choice of conceptual model for radionuclide transport in the Culebra (single porosity versus dual porosity, with and without chemical retardation). All cases are compared *ceteris paribus*, and all computational models and parameter values (both fixed and sampled), except those used in the conceptual models being compared, are identical throughout. All releases from groundwater transport are calculated at the subsurface projection of the land-withdrawal boundary (see Section 1.1 of this volume), 2.4 km south of the southern waste panels. Travel paths in the sampled transmissivity fields are not straight lines, and are somewhat greater in length than the minimum 2.4 km (LaVenue and RamaRao, 1992).

5.1.2.1.1 Intrusion Probability Models

The intrusion probability models are described in detail in Volume 2, Chapter 5 of this report. Both are based on the assumption that intrusion events will follow a Poisson process, and be random in time and space. One model, referred to as the "constant λ" model, is identical to that used in 1991 (WIPP PA Division, 1991a,b). The rate constant λ used in the Poisson model is assumed to be time-invariant, and is sampled from a uniform distribution with a range from zero to a maximum value that allows 30 boreholes/km^2 in 10,000 years. This upper limit is the number suggested by the EPA in Appendix B of the Standard as the largest probability of intrusion that need be considered (US EPA, 1985, p. 38089), which occurs in the Poisson model with a low probability. For the 70 vectors used in the 1992 analyses, the largest number of intrusions in the 0.5 km^2 of the waste-disposal area was 10, rather than the potential maximum of 15.

Guidance from the EPA in Appendix B of the Standard indicates that the DOE "should consider the effects of each particular disposal system's site, design, and passive institutional controls in judging the likelihood and consequences of ... inadvertent exploratory drilling" (US EPA, 1985, p. 38089). The second probability model, referred to as the "time-dependent λ" model, reflects the judgment of two expert panels convened by the WIPP

Performance Assessment Department to evaluate the likelihood of intrusion (Hora et al., 1991; memorandum by Hora in Volume 3, Appendix A of this report). Specifically, these panels considered (1) future societies and their means and motives for intruding into the WIPP, and (2) the design and potential efficacy of passive markers that might deter such intrusion. Judgment elicited from these panels was used to construct an alternative probability model for human intrusion (memorandum by Hora in Volume 3, Appendix A of this report). Two important aspects of the model need emphasis. First, the expert panels did not believe intrusions were equally likely at all times during the 10,000-year period; the rate constant λ therefore varies as a function of time. Intrusions are in general more likely at early times. The panel judged that exploratory drilling and hydrocarbon development would be likely to end in the next 300 to 500 years because of resource depletion and/or shifting from a hydrocarbon-based economy. Second, the expert panels concluded that intrusion was not as likely as suggested by the EPA's guidance on the maximum number of boreholes. The overall probability of intrusion based on the expert judgment is significantly less than that predicted by the constant λ model; the largest number of intrusions occurring in 10,000 years in any of the 70 vectors using the time-dependent λ model was 4.

5.1.2.1.2 Mode of Release

As in previous performance assessments, the 1992 results include two modes of radionuclide release following human intrusion. Particulate waste intersected by the drill bit (cuttings) and eroded from the borehole wall by circulating drilling fluid (cavings) will be brought directly to the ground surface. The radionuclides contained in this material are collectively referred to here as cuttings. Radionuclide releases to the accessible environment may also occur in the subsurface, as a result of brine flow up the borehole and laterally through the Culebra. Modeling of both pathways is described in detail in Volume 2 of this report.

Cuttings releases, which reach the accessible environment immediately following intrusion, are sensitive to the radioactive decay history of the inventory during the first 1000 years after decommissioning. Subsurface releases, which require a relatively long period of transport to the accessible environment, are believed to be less sensitive to the time of intrusion because decay will continue to occur during transport. The 1992 performance assessment therefore uses different times of intrusion for cuttings and subsurface releases. Greater resolution is provided for cuttings releases, with intrusions considered at six times (100, 175, 350, 1000, 3000, and 7250 years after decommissioning). Only a single intrusion time (1000 years after decommissioning) is considered for subsurface releases. This is the same intrusion time used in sensitivity analyses for groundwater transport used in the 1991 performance assessment (Helton et al., 1992).

5.1.2.1.3 Alternative Conceptual Models for Radionuclide Transport in the Culebra

Radionuclide transport in the Culebra is described in detail in Volume 2, Section 7.6 of this report. Three alternative conceptual models are considered here. These alternative conceptual models are defined on the basis of the presence or absence of chemical retardation, the presence or absence of clay linings in fractures, and the presence or absence of effective matrix porosity.

In the first conceptual model, referred to as the "fracture-only, K_d=0" model, the Culebra is treated as a single-porosity medium with transport occurring only in fractures without clay linings. Distribution coefficients (K_ds) are assumed to be zero, and neither physical nor chemical retardation occurs. This model is not believed to be realistic and is not supported by available data (Kelley and Pickens, 1986; Saulnier, 1987; Beauheim, 1987a,b, 1989; Jones et al., 1992). The model represents one endpoint of a continuum of possible models, and is examined to provide insights about the potential uncertainty introduced into the performance assessment by the lack of knowledge about transport processes in the Culebra.

The second conceptual model, referred to as the "dual-porosity, K_d=0" model, treats the Culebra as a dual-porosity medium, with transport occurring in clay-lined fractures and diffusion occurring into the pore volume of both the clay lining and the dolomite matrix. Distribution coefficients (K_ds) are assumed to be zero, and no chemical retardation occurs. The dual-porosity model is supported by available data from well tests (Kelley and Pickens, 1986; Saulnier, 1987; Beauheim, 1987b,c, 1989; Jones et al., 1992). Chemical retardation is believed likely to occur (Trauth et al., 1992), but experimental data are not available to provide defensible estimates of K_ds. This model is examined in part in fulfillment of the requirements of the Agreement for Consultation and Cooperation between the Department of Energy and the State of New Mexico (US DOE and the State of New Mexico, 1981, as modified), which states that "[i]n the absence of experimentally justifiable values, K_d will equal zero, i.e., no credit for retardation will be taken in the performance assessment calculations."

The third conceptual model, referred to as the "dual-porosity, $K_d \neq 0$" model, is identical to the second conceptual model except that chemical retardation does occur by sorption in both the clay linings and the dolomite matrix. The WIPP Performance Assessment Department believes that this model provides the most realistic representation of radionuclide transport in the Culebra. The model cannot, however, be fully supported by available data, nor can the alternative conceptual models presented above be fully refuted at this time. Experimental programs, including laboratory-scale radioactive tracer tests in progress in core samples from the Culebra (US DOE, 1992b, and references cited therein) and nonradioactive tracer tests planned for well locations in the Culebra (Beauheim and Davies, 1992), will provide data to reduce uncertainty in the conceptual model for transport in the Culebra.

These three conceptual models do not represent all possible combinations of the three criteria used to define the transport model. Dual-porosity models are also possible in which either clay linings or matrix porosity are absent. Results calculated using these models are discussed in Volume 4 of this report, together with more detailed analysis of the three conceptual models examined here.

5.1.2.2 RESULTS OF THE PRELIMINARY COMPARISON WITH THE CONTAINMENT REQUIREMENTS

The uncertainty introduced into cuttings releases by the choice of intrusion probability model is displayed in Figure 5-1. Cuttings are calculated for six times of intrusion. Probabilities are lower for the time-dependent λ (λ_t) case. As in previous performance assessments, plateau-shaped steps in both curves reflect the use of different activity-load categories (Helton et al., 1992). The larger number of intrusions occurring for the constant λ (λ_o) case results in a smoother appearance. Curves converge at low probabilities because those portions of the mean CCDFs are dominated by releases from the low-permeability intrusions that intersect waste of the highest activity levels.

Cuttings releases were recalculated for a single time of intrusion 1000 years after decommissioning to permit useful comparisons and combinations with the subsurface releases calculated for intrusion at the same time. Comparison of the cuttings-only CCDFs calculated for the constant λ case for six times of intrusion and a single time of intrusion provides a measure of the information gained by considering releases from intrusions at multiple times (Figure 5-2). Both probability and magnitude of normalized releases are increased by less than one order of magnitude when

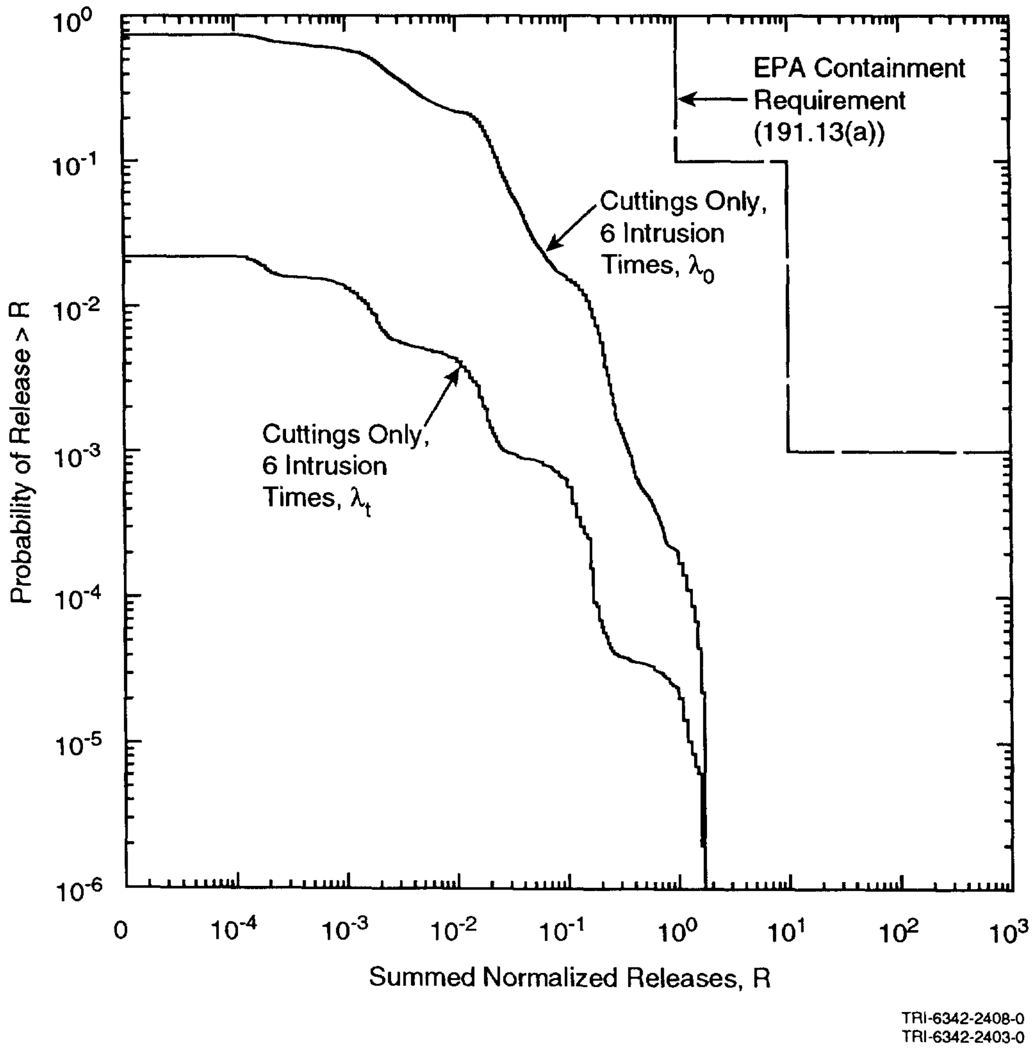


Figure 5-1. Mean CCDFs calculated for cuttings releases only for six intrusion times. Two Poisson models for the probability of human intrusion are compared: one (λ_0) is a constant λ model in which a maximum of 30 boreholes/km^2 may occur in 10,000 years; the other (λ_t) is a time-dependent λ model in which the Poisson rate constant λ was based on expert panel judgment. In both cases λ was specified using a sampled variable that was different for each of the 70 vectors used to construct the CCDFs. Summed normalized releases are displayed using an inverse hyperbolic sine scale, which differs from a logarithmic scale only in the interval between 0 and 10^{-4}.

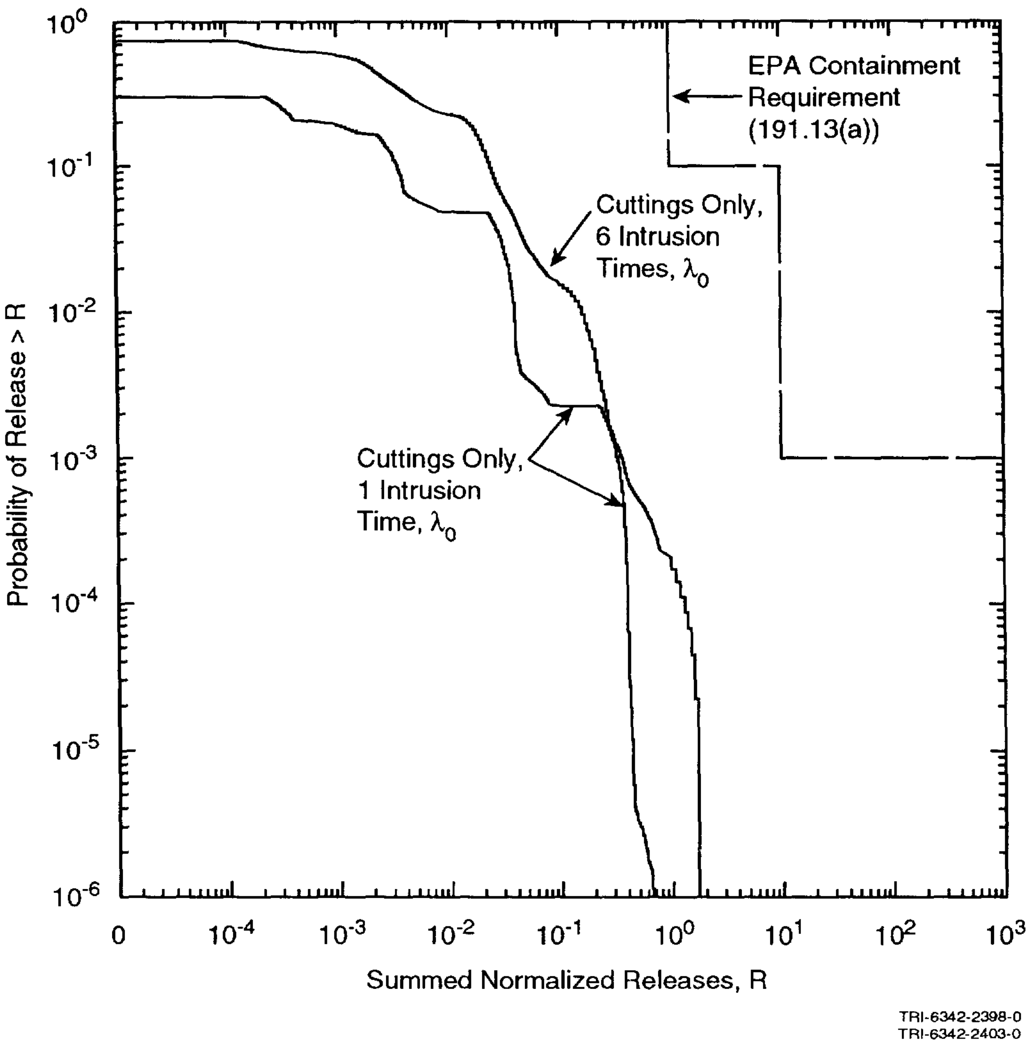


Figure 5-2. Mean CCDFs calculated for cuttings releases only, displaying the effect of considering a single time of intrusion versus six intrusion times. Both CCDFs were calculated using the constant λ model. Summed normalized releases are displayed using an inverse hyperbolic sine scale, which differs from a logarithmic scale only in the interval between 0 and 10^{-4}.

intrusions at multiple times are considered. Although releases from groundwater transport were not calculated for multiple time intervals in 1992, a similar comparison was made for subsurface releases from a dual-porosity model in the 1991 performance assessment. Examination of Figures 4.1-2 (lower right frame) and Figure 5.1-4 (lower right frame) in Helton et al. (1992) indicates that considering multiple time of intrusion (five intervals in 1991) increases both probability and magnitude of low-consequence releases less than one order of magnitude.

For the single-porosity, fracture-only conceptual model for transport used in 1992, subsurface releases exceed cuttings releases in the low-probability, high-consequence portion of the CCDF (Figure 5-3). The smaller subsurface releases occur at a lower probability than the comparable cuttings releases because not all intrusions resulted in releases into the Culebra. No releases occurred in vectors where the repository was not brine saturated at the time of intrusion and did not completely resaturate with brine following intrusion, because brine from the waste-disposal area did not flow up the borehole. Comparison of the CCDFs for cuttings and subsurface releases indicates that, if the effects of neither physical nor chemical retardation in the Culebra are included in the analysis, radionuclide transport in the Culebra may be the mechanism most likely to affect compliance with § 191.13 (Figure 5-3a). Even for the higher probability, constant λ case, however, the mean CCDF for cuttings and subsurface combined transport lies below the EPA limits (Figure 5-3b).

Use of the dual-porosity, $K_d=0$ conceptual model for radionuclide transport results in a reduction of subsurface releases compared to those estimated using the single-porosity model (Figure 5-4). For the constant λ case, the inclusion of physical retardation (but not, in this example, chemical retardation) shifts the location of the mean CCDF significantly in the region likely to affect regulatory compliance. For the time-dependent λ case, the lower overall probability of intrusions causes the main divergence between the single- and dual-porosity curves to occur at low probabilities, off the scale used here. This observation suggests that compliance with § 191.13 may be less sensitive to assumptions about the conceptual model for transport in the Culebra for lower intrusion probabilities.

Including the effects of chemical retardation as well as physical retardation (the dual-porosity, $K_d \neq 0$ conceptual model for transport) results in releases that are further reduced below those estimated assuming only physical retardation (Figure 5-5). Subsurface releases for the $K_d \neq 0$ conceptual model are less than the estimated cuttings releases at all probabilities (for the time-dependent λ case, the mean CCDF indicates no releases at this scale); the location of the mean CCDFs is determined

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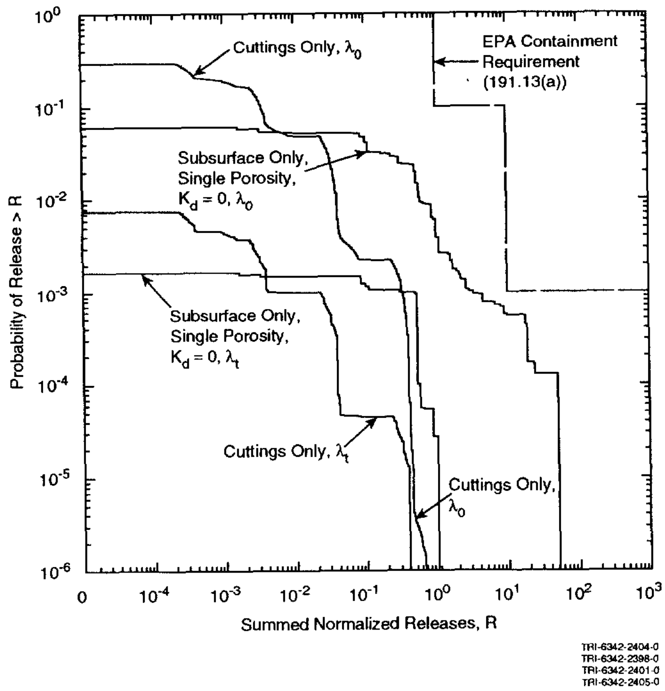
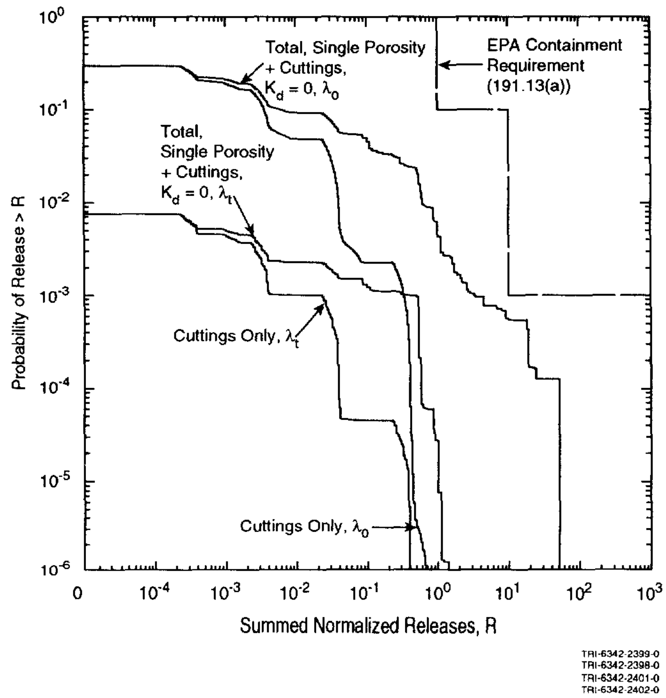


(a)



(b)

Figure 5-3. Comparison of mean CCDFs for cuttings releases and releases resulting from subsurface transport in the Culebra from intrusions occurring at 1000 years assuming a single-porosity, fracture-only conceptual model for transport. Figure 5-3a compares cuttings-only and subsurface-only releases. Figure 5-3b compares cuttings-only releases with total releases. Both constant λ and time-dependent λ cases are shown. Summed normalized releases are displayed using an inverse hyperbolic sine scale, which differs from a logarithmic scale only in the interval between 0 and 10^{-4}.

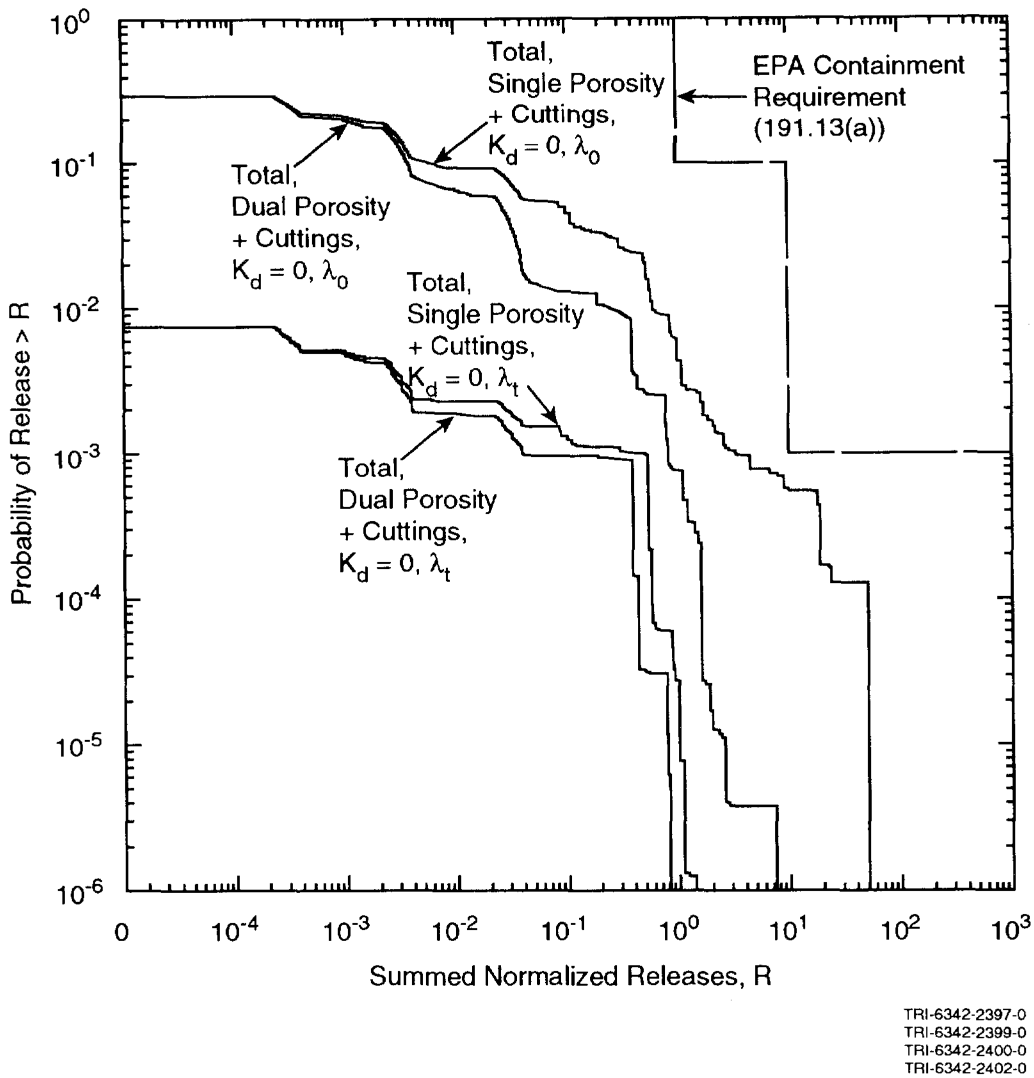


Figure 5-4. Comparison of mean CCDFs for total (cuttings plus subsurface) releases from intrusions occurring at 1000 years for single-porosity and dual-porosity, K_d=0 conceptual models for transport in the Culebra. Both constant λ and time-dependent λ cases are shown. Summed normalized releases are displayed using an inverse hyperbolic sine scale, which differs from a logarithmic scale only in the interval between 0 and 10^{-4}.

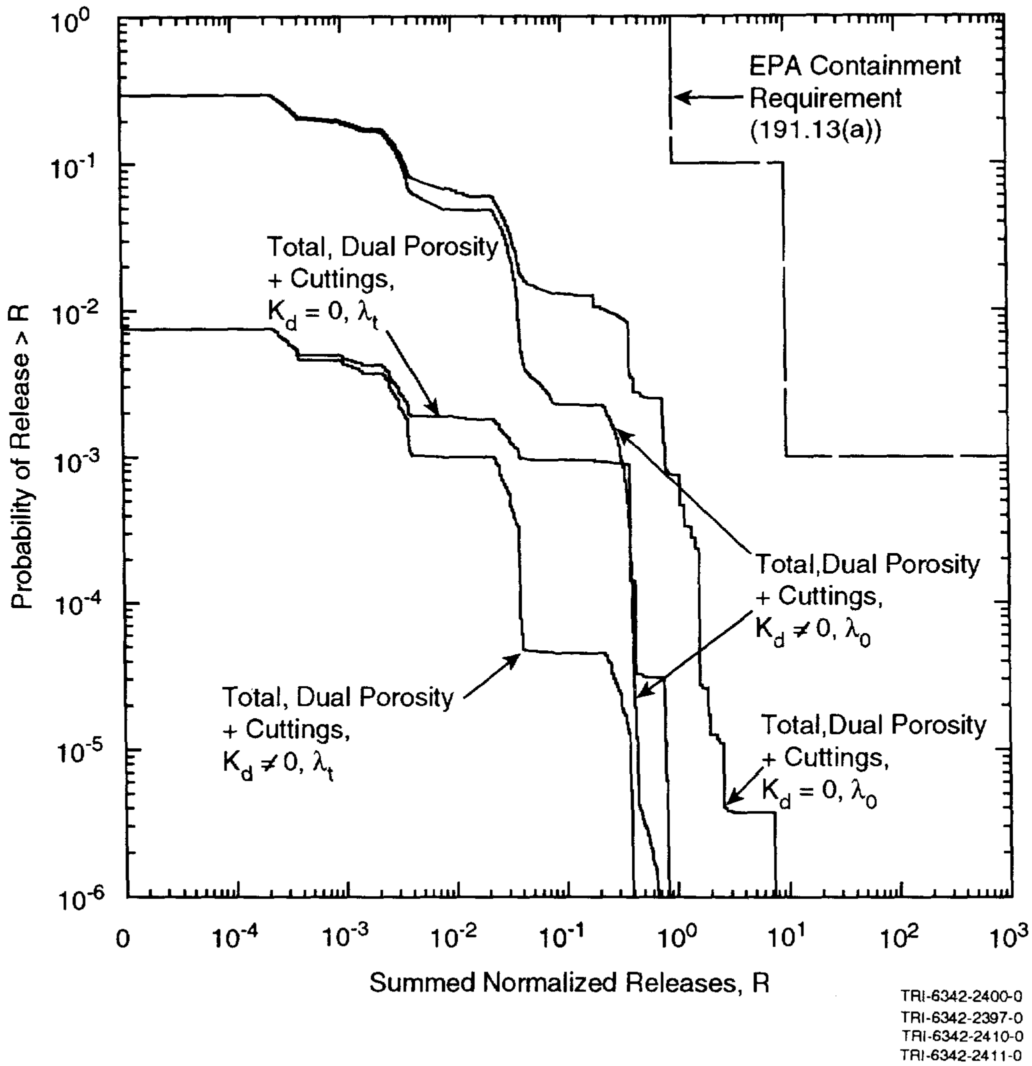


Figure 5-5. Comparison of mean CCDFs for total (cuttings plus subsurface) releases from intrusions occurring at 1000 years for dual-porosity, K_d=0 and dual-porosity, $K_d \neq 0$ conceptual models for transport in the Culebra. Both curves shown for $K_d \neq 0$ are dominated completely by cuttings releases. Both constant λ and time-dependent λ cases are shown. Summed normalized releases are displayed using an inverse hyperbolic sine scale, which differs from a logarithmic scale only in the interval between 0 and 10^{-4}.

entirely by the cuttings releases (compare to Figure 5-3a). K_d values used in these calculations were sampled from the same ranges used in the 1991 performance assessment, and are based on judgment elicited from a panel of SNL experts. K_d values used in a final compliance evaluation will be based on experimental data (US DOE, 1992b, and references cited therein).

5.1.2.3 DISCUSSION OF THE 1992 PRELIMINARY COMPARISON WITH THE CONTAINMENT REQUIREMENTS

Results presented in the preceding section are consistent with the conclusion made in previous preliminary comparisons that performance estimates for the WIPP lie below the limits set by the Containment Requirements (Bertram-Howery et al., 1990; WIPP PA Division, 1991a). As illustrated in Figure 5-6, consideration of alternative models for the probability of human intrusion and radionuclide transport in the Culebra provides insights into the relative impacts on performance of specific components of the natural barrier system and institutional controls at the WIPP.

The uppermost CCDF in Figure 5-6, labeled "Total, Single Porosity + Cuttings, λ_0" and calculated using the single-porosity and constant λ models, represents an estimate of the performance of the disposal system with very little contribution from the natural barrier provided by retardation in the Culebra and no contribution from the potential institutional barrier that could be provided by passive markers, as required by the Assurance Requirements. For the modeling system and data base used in 1992, the mean CCDF for this case lies below the EPA limits.

The segments of a CCDF shown with a dotted line and labeled "Total, Discharge from Borehole + Cuttings, λ_0" display performance with *no* contribution whatsoever from retardation in the Culebra. This CCDF is unlike all others shown in this volume in that releases are not calculated at the accessible environment, and therefore is not suitable for comparison, preliminary or otherwise, with the Containment Requirements. The curve displays releases directly into the Culebra (with cuttings also included) from boreholes occurring at 1000 years, and therefore provides an estimate of total releases if subsurface transport to the accessible environment were instantaneous and complete. The curve shows repository performance estimated with contributions from only the natural barrier provided by the Salado Formation and the engineered barrier system. Instantaneous and complete transport in the Culebra is physically unrealistic, and this curve is displayed only for the purpose of comparison with the curve described in the previous paragraph, which was calculated

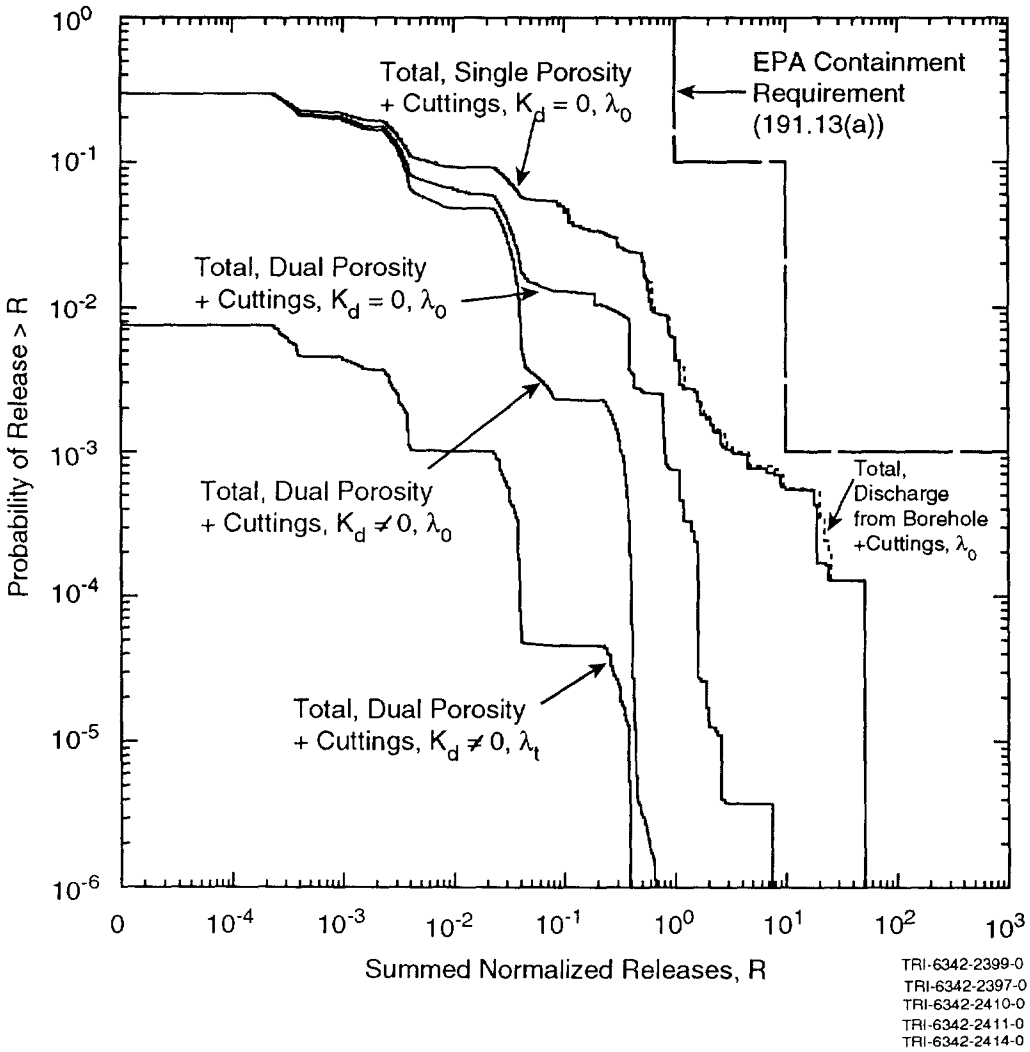


Figure 5-6. Comparison of mean CCDFs for total (cuttings plus subsurface) releases from intrusions occurring at 1000 years showing the impact of including specific components of the natural and institutional barrier systems. Both curves shown for $K_d \neq 0$ are dominated completely by cuttings releases. Summed normalized releases are displayed using an inverse hyperbolic sine scale, which differs from a logarithmic scale only in the interval between 0 and 10^{-4}.

using the single-porosity and constant λ models. The two curves are identical for most of their lengths. The differences between the curves are caused by radioactive decay during transport, and rapid transport in the single-porosity transport model in effect allows all sufficiently long-lived radionuclides that enter the Culebra to be released to the accessible environment within the 9000 years following intrusion.

The CCDF in Figure 5-6 labeled "Total, Dual Porosity + Cuttings, K_d=0, λ_o," represents an estimate of the performance of the disposal system if physical retardation by diffusion into the pore volume of the Culebra is included as a part of the natural barrier system. The area between the first and second CCDFs is a measure of the potential regulatory impact of including physical retardation. Similarly, the next CCDF in Figure 5-6, calculated using the dual-porosity, $K_d \neq 0$, and constant λ models, represents an estimate of the performance of the disposal system if both physical and chemical retardation in the Culebra are included in the natural barrier system. The location of this third curve is determined entirely by cuttings releases.

The final CCDF in Figure 5-6, calculated using the dual-porosity, $K_d \neq 0$, and time-dependent λ models, shows the effect of including expert judgment on the efficacy of passive markers in reducing the probability of human intrusion. This final CCDF, also determined entirely by cuttings releases, was calculated using what the WIPP Performance Assessment Department believes at this time to be the most realistic conceptual model for the disposal system, based on models and data available in 1992. As indicated previously, results are preliminary, and none of the curves shown in Figure 5-6 are believed sufficiently defensible for use in a final compliance evaluation.

5.2 Individual Protection Requirements

The Standard requires that an uncertainty analysis of undisturbed conditions be performed to assess compliance with the Individual Protection Requirements. In the case of the WIPP, the performance measure is dose to humans in the accessible environment.

Thus far, evaluations indicate that radionuclides will not migrate to the accessible environment boundary during 1000 years. Therefore, dose calculations are not expected to be a part of the WIPP assessment of compliance with the Standard. However, Subpart B is in remand. Performance assessments will continue to evaluate compliance with the Individual Protection Requirements of the 1985 Standard until a revised Standard is promulgated.

5.2.1 Previous Studies

Three previous studies reported doses to humans resulting from hypothetical releases from the WIPP for selected scenarios (US DOE, 1980a; Lappin et al., 1989, 1990). Although these studies employed deterministic calculations and were not concerned with assessing compliance with the Individual Protection Requirements, they had an important influence on the design of probability-based dose calculations. An uncertainty analysis of undisturbed performance was performed in a methodology demonstration for WIPP performance assessment (Marietta et al., 1989). The relative importance of various phenomena and system components was examined through sensitivity analyses of four different repository/shaft models for undisturbed conditions (Rechard et al., 1990b). Calculations for undisturbed performance of the repository were not updated in the 1990 preliminary performance assessment (Bertram-Howery et al., 1990). However, information about possible effects of gas generated within the repository was obtained from the assessment of disturbed performance.

The approach adopted for the 1991 preliminary performance assessment was to perform deterministic calculations to verify that, using the 1991 modeling system, previous conclusions of no releases in 10,000 years were still valid. First, a two-dimensional horizontal simulation to assess the migration of brine from the repository into the intact portion of MB139 was performed. The calculation estimated the spatial scale that passive, neutrally buoyant particles would be transported in advecting brine as a result of maximum gas-generation rates in a waste panel. Second, a two-dimensional simulation of a vertical section of the repository from waste panels to the closest shaft was performed to assess migration of radionuclides through the DRZ, panel seals, and backfilled excavations. The calculation estimated the extent that radionuclides would be transported in brine flowing toward and upward through sealed shafts as a result of the pressure gradient between the Culebra Dolomite and a waste panel that is pressurized with waste-generated gas. Least favorable bounds for important parameter values (e.g., an inexhaustible source, no decay, no retardation, the same solubility limit for all radionuclides, etc.) were assumed.

Results of the horizontal simulation showed concentrations at 120 m from the panels in the intact MB139 after 10,000 years to be 1 percent of the source. Results of the vertical simulation including the shaft showed EPA normalized sums (consequences) at 10,000 years of less than 10^{-2} at 20 m up the shaft and less than 10^{-3} at 50 m up the shaft. The 1991 preliminary performance assessment indicated that no significant releases occur at the shaft/Culebra intersection at 10,000 years.

Sensitivity analyses of gas and brine migration provide further support for the preliminary conclusion that radionuclides will not migrate to the accessible environment from the undisturbed repository (WIPP PA Department, 1992). These analyses of 10,000-year undisturbed performance used a two-dimensional vertical cross-section of the repository that included a simplified representation of the shaft and shaft-seal system, and examined flow of both brine and gas up the shaft and horizontally through anhydrite interbeds toward the accessible environment. Analyses did not include salt creep or pressure-dependent fracturing of anhydrite interbeds. Because these analyses were primarily designed to provide guidance to the WIPP Project for use in developing a strategy for evaluating compliance with the RCRA (specifically, with 40 CFR 268.6, which states the conditions for land disposal of hazardous wastes), emphasis was placed on gas migration, and radionuclide transport was not included in the calculations. However, in the selected analyses in which brine flow was tracked from the waste panels, no brine that had been in contact with waste migrated past the disturbed rock zone in 10,000 years. Because the only significant transport of radionuclides from the WIPP will occur in brine, analyses of brine migration provide an approximation of the maximum distance radionuclides may travel.

5.2.2 1992 Preliminary Comparison

Results of the 1992 preliminary performance assessment for informal comparison with the Individual Protection Requirements will be reported in Volume 4 of this report.

5.3 Assurance Requirements

As prescribed in the Agreement for Consultation and Cooperation with the State of New Mexico (US DOE and State of New Mexico, 1981, as modified), the WIPP Project has prepared a plan for implementing the Assurance Requirements of the 1985 Standard (US DOE, 1987). The plan is preliminary because methods and technologies could evolve over the waste-emplacement time frame. A draft of the revised ***Assurance Requirements Plan*** (US DOE, 1987) is in review; however, the information in the following sections is from the 1987 version unless otherwise noted. In accordance with the Project's interpretation of the EPA's intention, the Project will select assurance measures based on the uncertainties in the final performance assessment. The current plan includes definitions and clarifications of the Standard as it applies to the WIPP, the implementation objective for each requirement, an outline of the implementation steps for each requirement, and a schedule of activities leading to final compliance. Additional information on markers as passive institutional controls comes from performance-assessment activities using expert panels.

5.3.1 Active Institutional Controls

Active institutional controls are expected to include evaluation of land use in the WIPP area; maintaining fences and buildings and guarding the facility during active cleanup; decontamination and decommissioning; land reclamation; and post disposal-phase monitoring. The objectives of these activities are to provide a facility and presence at the site during active cleanup; to restore the land surface as closely to its original condition as possible to avoid future preferential selection of the area for incompatible uses, if restoration is deemed desirable after consideration of the results of the expert panel on markers (see Section 5.3.3 of this volume); and to monitor the disposal system.

Performance assessments may assume that active control is maintained for 100 years; in the 1992 calculations, no intrusions are assumed to occur during the first 100 years after decommissioning.

5.3.2 Disposal-System Monitoring

Monitoring is required until no significant concerns need to be addressed by further monitoring. The objective of the monitoring program is "to detect substantial and detrimental deviation from the expected performance of the disposal system" (§ 191.14(b)). Monitoring activities will be identified during the course of the performance assessment, but are likely to include monitoring of hydrological, geological, geochemical, and structural performance. Monitoring that jeopardizes the isolation capabilities of the disposal system is not allowed. Numerous survey monuments have been installed to monitor subsidence as an indicator of unexpected changes in the disposal system.

5.3.3 Passive Institutional Controls

The Project will implement passive institutional controls over the entire controlled area of the WIPP. Passive institutional controls include markers warning of the presence of buried nuclear waste and identifying the boundary of the controlled area, external records about the WIPP repository, and continued federal ownership. The EPA assumes in the guidance to the Standard that passive institutional controls will reduce the possibility of inadvertent human intrusion into the repository. Compliance evaluation for the Standard must address the potential for human intrusion and the effectiveness of passive institutional controls to deter such intrusion.

To address the issues of markers for the WIPP, two expert panels were established. Members of the first panel identified possible future societies and how they may intrude the repository, and also developed probabilities of future society development and of various intrusions (Hora et al., 1991). The possible modes of intrusion identified by the first panel were provided to a second panel as an aid in developing design characteristics for permanent markers and judging the efficacy of the markers in deterring human intrusion. A report about the "markers" panel is currently being prepared. In addition, a report is in preparation that describes past efforts at developing barriers to human intrusion, as a complement to the markers.

Records will be preserved of the disposal site and its contents. The expert panel on intrusion into the repository considered the impact of records preservation on intrusion rates and probabilities (Hora et al., 1991). The panel indicated that records should specify techniques for borehole plugging in the event that exploratory drilling caused an intrusion. Such techniques could be incorporated into legal records together with the description and location of the disposal system. The records could also contain a warning about the potential effects of drilling through the repository and into pressurized brine in the Castile Formation.

In accordance with Appendix B of the Standard, the DOE or some successor agency is assumed to retain ownership and administrative control over the WIPP area. The federal agency responsible for the land will institute regulations that appropriately restrict land use and development. Acreage around the WIPP is owned by the Federal government and currently administered by the DOE. The area within the land-withdrawal boundary for the WIPP is withdrawn from all forms of entry, appropriation, and disposal under the public land laws, including the mineral leasing laws, the geothermal leasing laws, the material sale laws, and the mining laws (Public Law 102-579, 1992, Section 3). With respect to drilling, the DOE has control of the acreage within the land-withdrawal boundary from the surface to 6000 ft (1830 m) in the subsurface. Additionally, grazing may continue to the extent that it is compatible with WIPP activities.

5.3.4 Multiple Barriers

The Standard requires that both natural and engineered barriers be used as part of the isolation system. At the WIPP, natural barriers include the favorable characteristics of the salt formation and the geohydrologic setting. Engineered barriers that will isolate wastes from the accessible environment will include seals in repository excavations and bentonite and crushed-salt backfill in waste-emplacement panels. The effectiveness of these barriers is being modeled for the performance assessment to determine if they will provide a disposal system that isolates the radioactive wastes to the levels required in the Standard. In addition, the Engineered Alternatives Task Force has evaluated additional engineering measures for the WIPP, should such measures be necessary (US DOE, 1990e, 1991d).

5.3.5 Natural Resources

The Standard requires that locations containing recoverable resources not be used for repositories unless the favorable characteristics of a proposed location can be shown to compensate for the greater likelihood of being disturbed in the future. Evaluation of the natural resources in the WIPP area centers on two issues: (1) the denial of resources that could not be developed because such development might conflict with the long-term goal of waste isolation, and (2) the attractiveness to future generations of resources associated with the location. Future societies might attempt to exploit natural resources near the WIPP and thereby create the potential for a release of radionuclides into the accessible environment. These issues have been evaluated in several reports (US DOE, 1980a, 1981; US DOE and State of New Mexico, 1981, as modified; Brausch et al., 1982; Weart, 1983; US DOE, 1990d). A recent report summarizes these earlier reports (US DOE, 1991c), and the DOE will continue to document information about natural resources that was used in making the decision to proceed with the WIPP Project.

5.3.6 Waste Removal

The Standard requires that disposal systems be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal (§ 191.14(f)). A primary plan for waste removal during the disposal phase of the WIPP (Subpart A of the Standard) has been prepared (US DOE, 1980a). In promulgating the Standard, the EPA stated that to meet the waste-removal requirement for the post-closure phase (Subpart B of the Standard), it only need be technologically feasible to be able to mine the sealed repository and recover the waste, even at substantial cost and occupational risk (US EPA, 1985, p. 38082). The EPA also stated that "*any* current concept for a mined geologic repository meets this requirement *without* any additional procedures or design features" (US EPA, 1985, p. 38082, emphasis in original). Thus, the WIPP satisfies this requirement.

5.4 Groundwater Protection Requirements

The WIPP must comply with the Groundwater Protection Requirements of the Standard by providing a reasonable expectation that radionuclide concentrations in a "special source of ground water" will not exceed specified values (§ 191.16; also see Section 3.6 of this volume). Evaluations have indicated that the requirement is not relevant to the WIPP because no groundwater near the WIPP within the maximum areal extent designated by the Standard (Figure 3-4) satisfies the definition of a "special source of groundwater."

Based upon the EPA definition of Class I groundwater (US EPA, 1984) as used in the definition of special source of groundwater, for Class I groundwater to be present at the WIPP, the groundwater resource must be highly vulnerable to contamination because of the hydrogeological characteristics of the areas under which the resource occurs, including areas of high hydraulic conductivity or areas of groundwater recharge. Either of the following must also be true: the groundwater must be an irreplaceable source of drinking water, or the groundwater must be ecologically vital.

The hydrogeological characteristics of the WIPP have been evaluated through extensive ongoing investigations dating to 1975 (US DOE, 1990c). Groundwater quality and the hydrologic conductivity of water-bearing units at the WIPP are monitored and reported annually (Lyon, 1989). The most transmissive hydrologic unit in the WIPP area is the Culebra Dolomite Member of the Rustler Formation (see Chapter 2 of this volume and Volume 2 of this report). Hydraulic properties of the Culebra Dolomite have been calculated from test holes in the vicinity of the WIPP (summarized in Cauffman et al., 1990, and Brinster, 1991). Horizontal groundwater flow in the Culebra away from the WIPP is generally to the south along a decreasing gradient at a very slow rate. Based on hydrogeological studies in the WIPP area, no geological units with high hydraulic conductivities that would require special protective measures appear to be present (Marietta et al., 1989; Lappin et al., 1989; US DOE, 1990c). If groundwater that is highly vulnerable to contamination were present near the WIPP, it would not be classified as Class I because it is neither an irreplaceable source of drinking water for a substantial population (Lappin et al., 1989) nor ecologically vital (US DOE, 1980a, 1991c).

Even if Class I groundwater were present at the WIPP, the Groundwater Protection Requirements would be relevant only if the groundwater were supplying drinking water to thousands of persons at the date DOE selected the site for development of the WIPP *and* if these groundwaters were irreplaceable. At the time the DOE chose the WIPP location, and currently, no source of water (including Class I groundwater) within 5 km (3 mi) beyond the maximum allowable extent of the controlled area was supplying drinking water for thousands (or even tens) of persons. Thus, even if Class I groundwater were present, the Groundwater Protection Requirements would not be relevant to the WIPP.

6. CONCLUSIONS

The 1992 preliminary comparison with 40 CFR 191, Subpart B, for the WIPP is consistent with the conclusions from the 1990 and 1991 preliminary comparisons (Bertram-Howery et al., 1990; WIPP PA Division, 1991a): based on the presently available conceptual models, computational models, and data describing disposal-system performance, the WIPP Performance Assessment Department has a high level of confidence that the WIPP will be able to comply with the quantitative requirements of the Standard as promulgated in 1985 (US EPA, 1985). As summarized in the following discussion, however, the modeling system and data base are still incomplete; results therefore remain preliminary and should not be used for a formal comparison with the Standard. Furthermore, the Standard has been vacated by a Federal Court of Appeals (NRDC v. US EPA, 1987). The Standard will be repromulgated in 1993, as specified by the *WIPP Land Withdrawal Act* (Public Law 102-579, 1992), and may differ in some aspects from the 1985 version on which the 1992 preliminary comparison is based. The WIPP Performance Assessment Department anticipates that a final, defensible performance assessment suitable for compliance evaluation will be completed following additional iterations of preliminary performance assessments.

The 1992 performance-assessment calculations reflect improvements in several important portions of the modeling system. Specific major improvements in the modeling system for 1992 (described in detail in Volume 2 of this report) are: the inclusion of the effects of salt creep in the modeling of disposal-room behavior; the use of an advanced geostatistical procedure to account for spatial variability in the transmissivity of the Culebra Dolomite Member of the Rustler Formation; and the use of a computational model for radionuclide transport in the Culebra that allows consideration of alternative conceptual models for dual-porosity and single-porosity transport. The 1992 performance assessment also marks the first use of judgment elicited from expert panels to determine the probability of future inadvertent human intrusion into the WIPP (see Volume 2, Chapter 5 of this report, and the memorandum by Hora in Volume 3, Appendix A of this report).

Results of the 1992 preliminary comparison with the Containment Requirements of the Standard (§ 191.13) are presented as mean complementary cumulative distribution functions (CCDFs) displaying estimated probabilistic releases of radionuclides to the accessible environment for 10,000 years. Results compare three conceptual models for radionuclide transport in the Culebra and two approaches to estimating the probability of inadvertent human intrusion into the WIPP by exploratory drilling. The representation for disposal-system performance believed by the WIPP Performance Assessment Department to be most realistic includes intrusion probabilities based on expert-panel judgment and dual-porosity transport with chemical retardation. For intrusions occurring 1000 years after decommissioning, the mean CCDF for this representation lies more than one order of magnitude below the EPA limits. Using the same approach to intrusion probabilities used in the 1991 performance assessment (i.e., not taking expert judgment into account and basing the probability model on the maximum intrusion probability indicated in Appendix B of 40 CFR 191) significantly increases the probability of releases, regardless of the model used for subsurface transport. Assuming the higher intrusion probabilities and dual-porosity transport without chemical retardation, the mean CCDF is approximately one order of magnitude below the EPA limits. For the higher intrusion probabilities and single-porosity, fracture-only transport (which assumes very little contribution from the natural barrier provided by retardation in the Culebra), the mean CCDF is less than one order of magnitude below the EPA limits.

Performance estimates for the 1992 preliminary comparison with the Individual Protection Requirements of the Standard (§ 191.15) have not been included in this volume. Previous analyses indicate that no radionuclides will reach the accessible environment from the undisturbed repository for 10,000 years (Marietta et al., 1989). Calculations of brine and gas migration from the undisturbed repository completed using the 1991 performance-assessment modeling system suggest that brine (the only medium in which significant radionuclide transport will occur at the WIPP) that has been in contact with waste will not migrate more than a few tens of meters from the waste-emplacement panels in 10,000 years (WIPP PA Department, 1992). Determination of compliance with the Individual Protection Requirements as promulgated in 1985 will be based on estimates of doses to humans in the accessible environment for 1000 years (rather than 10,000 years) of undisturbed performance. Because no releases whatsoever to the accessible environment are predicted for 1000 years of undisturbed performance, no doses to humans are anticipated and determination of compliance with the Individual Protection Requirements should be straightforward.

The third quantitative requirement of the Standard, the Groundwater Protection Requirements (§ 191.16), does not apply to the WIPP because no "special source of ground water," as defined in the Standard, is present at the WIPP. All groundwater at the WIPP fails to meet more than one of the specified criteria, including the requirement that a "special source of ground water" be "supplying drinking water for thousands of persons as of the date that the [DOE] chooses a location..." and that the source of water be "irreplaceable" (§ 191.12(o)).

As noted above, several aspects of the modeling system and data base can be identified now as requiring additional work before the performance assessment can be considered defensible for a final comparison to the Standard. Information will be provided for specific needs (e.g., conceptual models or distributions for important parameters that are insufficiently supported by experimental data) by ongoing and planned laboratory and field experimental programs described in the *Test Phase Plan* (US DOE, 1990a, currently in revision). These needs include include the following: defensible values for radionuclide solubilities in repository brine; retardation factors for radionuclides in the Culebra; additional support for the dual-porosity model for transport in the Culebra; and an improved model for the generation of gas as waste and containers degrade. Other needs will be met by improvements in performance-assessment modeling. Conceptual and computational models will be developed for pressure-dependent fracturing of the anhydrite interbeds above and below the repository. Spalling of waste into an intruding borehole as the repository depressurizes will be examined and, if important, included in performance-assessment modeling. The consequences of brine flow to the surface following borehole intrusion will be modeled. Several aspects of groundwater flow in the Culebra will be examined as a three-dimensional model for regional groundwater flow becomes available, including the possible effects of subsidence related to potash mining, uncertainty resulting from the incomplete understanding of present recharge and vertical flow between units, and additional analyses of the effects of climatic change. Future analyses will also examine the effect on estimated performance of correlations that may exist between physical parameters that are currently assumed for the Monte Carlo simulations to be uncorrelated.

The WIPP Performance Assessment Department believes that future analyses will indicate that none of these identified needs will have a major impact on compliance with the quantitative requirements of the Standard. This belief cannot be supported defensibly at this time and is offered here as an opinion of the Performance Assessment Department, rather than as fact. It is based on the premise that the major processes that will contribute to radionuclide releases have already been identified and included in the performance-assessment modeling system. Although the performance-assessment needs identified now and listed above contribute to uncertainty in estimated performance, resolution of those needs is unlikely to shift the location of the mean CCDF beyond the range displayed in the 1992 results. Additional needs may be identified by future performance-assessment iterations and laboratory and field studies, but none is foreseen at this time to have an impact as great as that of those already identified.

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APPENDIX A:
TITLE 40, CODE OF FEDERAL REGULATIONS, SUBCHAPTER F, PART 191

APPENDIX A:
TITLE 40, CODE OF FEDERAL REGULATIONS
SUBCHAPTER F—RADIATION PROTECTION PROGRAMS

PART 191—ENVIRONMENTAL RADIATION PROTECTION STANDARDS FOR MANAGEMENT AND DISPOSAL OF SPENT NUCLEAR FUEL, HIGH-LEVEL AND TRANSURANIC RADIOACTIVE WASTES

Subpart A—Environmental Standards for Management and Storage

Authority: The Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act of 1982.

Subpart A—Environmental Standards for Management and Storage

§ 191.01 Applicability.

This Subpart applies to:

(a) Radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at any facility regulated by the

Nuclear Regulatory Commission or by Agreement States, to the extent that such management and storage operations are not subject to the provisions of Part 190 of title 40; and

(b) Radiation doses received by members of the public as a result of the management and storage of spent nuclear fuel or high-level or transuranic wastes at any disposal facility that is operated by the Department of Energy and that is not regulated by the Commission or by Agreement States.

§ 191.02 Definitions.

Unless otherwise indicated in this Subpart, all terms shall have the same meaning as in Subpart A of Part 190.

(a) "Agency" means the Environmental Protection Agency.

(b) "Administrator" means the Administrator of the Environmental Protection Agency.

(c) "Commission" means the Nuclear Regulatory Commission.

(d) "Department" means the Department of Energy.

(e) "NWPA" means the Nuclear Waste Policy Act of 1982 (Pub. L. 97-425).

(f) "Agreement State" means any State with which the Commission or the Atomic Energy Commission has entered into an effective agreement under subsection 274b of the Atomic Energy Act of 1954, as amended (68 Stat. 919).

(g) "Spent nuclear fuel" means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

(h) "High-level radioactive waste," as used in this Part, means high-level radioactive waste as defined in the Nuclear Waste Policy Act of 1982 (Pub. L. 97-425).

(i) "Transuranic radioactive waste," as used in this Part, means waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than twenty years, per gram of waste, except for: (1) High-level radioactive wastes; (2) wastes that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this Part; or (3) wastes that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61.

(j) "Radioactive waste," as used in this Part, means the high-level and transuranic radioactive waste covered by this Part.

(k) "Storage" means retention of spent nuclear fuel or radioactive wastes with the intent and capability to readily retrieve such fuel or waste for subsequent use, processing, or disposal.

(l) "Disposal" means permanent isolation of spent nuclear fuel or radioactive wastes from the accessible environment with no intent of recovery, whether or not such isolation permits the recovery of such fuel or waste. For example, disposal of waste in a mined geologic repository occurs when all of the shafts to the repository are backfilled and sealed.

(m) "Management" means any activity, operation, or process (except for transportation) conducted to prepare spent nuclear fuel or radioactive waste for storage or disposal, or the activities associated with placing such fuel or waste in a disposal system.

(n) "Site" means an area contained within the boundary of a location under the effective control of persons possessing or using spent nuclear fuel or radioactive waste that are involved in any activity, operation, or process covered by this Subpart.

(o) "General environment" means the total terrestrial, atmospheric, and aquatic environments outside sites within which any activity, operation, or process associated with the management and storage of spent nuclear fuel or radioactive waste is conducted.

(p) "Member of the public" means any individual except during the time when that individual is a worker engaged in any activity, operation, or process that is covered by the Atomic Energy Act of 1954, as amended.

(q) "Critical organ" means the most exposed human organ or tissue exclusive of the integumentary system (skin) and the cornea.

§ 191.03 Standards.

(a) Management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities regulated by the Commission or by Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from: (1) Discharges of radioactive material and direct radiation from such management and storage and (2) all operations covered by Part 190; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ.

(b) Management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities for the disposal of such fuel or waste that are operated by the Department and that are not regulated by the Commission or Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from discharges of radioactive material and direct radiation from such management and storage shall not exceed 25 millirems to the whole body and 75 millirems to any critical organ.

§ 191.04 Alternative standards.

(a) The Administrator may issue alternative standards from those standards established in 191.03(b) for waste management and storage activities at facilities that are not regulated by the Commission or Agreement States if, upon review of an application for such alternative standards:

(1) The Administrator determines that such alternative standards will prevent any member of the public from receiving a continuous exposure of more than 100 millirems per year dose equivalent and an infrequent exposure of more than 500 millirems dose equivalent in a year from all sources, excluding natural background and medical procedures; and

(2) The Administrator promptly makes a matter of public record the degree to which continued operation of the facility is expected to result in levels in excess of the standards specified in 191.03(b).

(b) An application for alternative standards shall be submitted as soon as possible after the Department determines that continued operation of a facility will exceed the levels specified in 191.03(b) and shall include all information necessary for the Administrator to make the determinations called for in 191.04(a).

(c) Requests for alternative standards shall be submitted to the Administrator, U.S. Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460.

§ 191.05 Effective date.

The standards in this Subpart shall be effective on November 18, 1985.

Subpart B—Environmental Standards for Disposal

§ 191.11 Applicability.

(a) This Subpart applies to:

(1) Radioactive materials released into the accessible environment as a result of the disposal of spent nuclear fuel or high-level or transuranic radioactive wastes;

(2) Radiation doses received by members of the public as a result of such disposal; and

(3) Radioactive contamination of certain sources of ground water in the vicinity of disposal systems for such fuel or wastes.

(b) However, this Subpart does not apply to disposal directly into the oceans or ocean sediments. This Subpart also does not apply to wastes disposed of before the effective date of this rule.

§ 191.12 Definitions.

Unless otherwise indicated in this Subpart, all terms shall have the same meaning as in Subpart A of this Part.

(a) "Disposal system" means any combination of engineered and natural barriers that isolate spent nuclear fuel or radioactive waste after disposal.

(b) "Waste," as used in this Subpart, means any spent nuclear fuel or radioactive waste isolated in a disposal system.

(c) "Waste form" means the materials comprising the radioactive components of waste and any encapsulating or stabilizing matrix.

(d) "Barrier" means any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment. For example, a barrier may be a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around waste, provided that the material or structure substantially delays movement of water or radionuclides.

(e) "Passive institutional control" means: (1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system.

(f) "Active institutional control" means: (1) Controlling access to a disposal site by any means other than passive institutional controls; (2) performing maintenance operations or remedial actions at a site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance.

(g) "Controlled area" means: (1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location.

(h) "Ground water" means water below the land surface in a zone of saturation.

(i) "Aquifer" means an underground geological formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring.

(j) "Lithosphere" means the solid part of the Earth below the surface, including any ground water contained within it.

(k) "Accessible environment" means: (1) The atmosphere; (2) land surfaces; (3) surface waters; (4) oceans; and (5) all of the lithosphere that is beyond the controlled area.

(l) "Transmissivity" means the hydraulic conductivity integrated over the saturated thickness of an underground formation. The transmissivity of a series of formations is the sum of the individual transmissivities of each formation comprising the series.

(m) "Community water system" means a system for the provision to the public of piped water for human consumption, if such system has at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

(n) "Significant source of ground water," as used in this Part, means: (1) An aquifer that: (i) Is saturated with water having less than 10,000 milligrams per liter of total dissolved solids; (ii) is within 2,500 feet of the land surface; (iii) has a transmissivity greater than 200 gallons per day per foot, provided that any formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than 2 gallons per day per square foot; and (iv) is capable of continuously yielding at least 10,000 gallons per day to a pumped or flowing well for a period of at least a year; or (2) an aquifer that provides the primary source of water for a community water system as of the effective date of this Subpart.

(o) "Special source of ground water," as used in this Part, means those Class I ground waters identified in accordance with the Agency's Ground-Water Protection Strategy published in August 1984 that: (1) Are within the controlled area encompassing a disposal system or are less than five kilometers beyond the controlled area; (2) are supplying drinking water for thousands of persons as of the date that the Department chooses a location within that area for detailed characterization as a potential site for a disposal system (e.g., in accordance with Section 112(b)(1)(B) of the NWPA); and (3) are irreplaceable in that no reasonable alternative source of drinking water is available to that population.

(p) "Undisturbed performance" means the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.

(q) "Performance assessment" means an analysis that: (1) Identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable.

(r) "Heavy metal" means all uranium, plutonium, or thorium placed into a nuclear reactor.

(s) "Implementing agency," as used in this Subpart, means the Commission for spent nuclear fuel or high-level or transuranic wastes to be disposed of in facilities licensed by the commission in accordance with the Energy Reorganization Act of 1974 and the Nuclear Waste Policy Act of 1982, and it means the Department for all other radioactive wastes covered by this Part.

§ 191.13 Containment requirements.

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and

(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

(b) Performance assessments need not provide complete assurance that the requirements of 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with 191.13(a) will be achieved.

§ **191.14 Assurance requirements.**

To provide the confidence needed for long-term compliance with the requirements of 191.13, disposal of spent nuclear fuel or high-level or transuranic wastes shall be conducted in accordance with the following provisions, except that these provisions do not apply to facilities regulated by the Commission (see 10 CFR Part 60 for comparable provisions applicable to facilities regulated by the Commission):

(a) Active institutional controls over disposal sites should be maintained for as long a period of time as is practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contributions from active institutional controls for more than 100 years after disposal.

(b) Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring.

(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location.

(d) Disposal systems shall use different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included.

(e) Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this Part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future.

(f) Disposal systems shall be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal.

§ 191.15 Individual protection requirements.

Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 millirems to the whole body or 75 millirems to any critical organ. All potential pathways (associated with undisturbed performance) from the disposal system to people shall be considered, including the assumption that individuals consume 2 liters per day of drinking water from any significant source of ground water outside of the controlled area.

§ 191.16 Ground water protection requirements.

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed:

(1) 5 picocuries per liter of radium-226 and radium-228;

(2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or

(3) The combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ greater than 4 millirems per year if an individual

consumed 2 liters per day of drinking water from such a source of ground water.

(b) If any of the average annual radionuclide concentrations existing in a special source of ground water before construction of the disposal system already exceed the limits in 191.16(a), the disposal system shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not increase the existing average annual radionuclide concentrations in water withdrawn from that special source of ground water by more than the limits established in 191.16(a).

§ 191.17 Alternative provisions for disposal.

The Administrator may, by rule, substitute for any of the provisions of Subpart B alternative provisions chosen after:

(a) The alternative provisions have been proposed for public comment in the **Federal Register** together with information describing the costs, risks, and benefits of disposal in accordance with the alternative provisions and the reasons why compliance with the existing provisions of Subpart B appears inappropriate;

(b) A public comment period of at least 90 days has been completed, during which an opportunity for public hearings in affected areas of the country has been provided; and

(c) The public comments received have been fully considered in developing the final version of such alternative provisions.

§ 191.18 Effective date.

The standards in this Subpart shall be effective on November 18, 1985.

Appendix A—Table for Subpart B

TABLE 1.—RELEASE LIMITS FOR CONTAINMENT REQUIREMENTS

(Cumulative releases to the accessible environment for 10,000 years after disposal)

Radionuclide	Release limit per 1,000 MTHM or other unit of waste (see notes) (curies)
Americium-241 or -243	100
Carbon-14	100
Cesium-135 or -137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, -239, -240, or -242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or -232	10
Tin-126	1,000
Uranium-233, -234, -235, -236, or -238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000

Application of Table 1

Note 1: *Units of Waste.* The Release Limits in Table 1 apply to the amount of wastes in any one of the following:

(a) An amount of spent nuclear fuel containing 1,000 metric tons of heavy metal (MTHM) exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal (MWd/MTHM) and 40,000 MWd/MTHM;

(b) The high-level radioactive wastes generated from reprocessing each 1,000 MTHM exposed to a burnup between 25,000 MWd/MTHM and 40,000 MWd/MTHM;

(c) Each 100,000,000 curies of gamma or beta-emitting radionuclides with half-lives greater than 20 years but less than 100 years (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA);

(d) Each 1,000,000 curies of other radionuclides (i.e., gamma or beta-emitters with half-lives greater than 100 years or any alpha-emitters with half-lives greater than 20 years) (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA); or

(e) An amount of transuranic (TRU) wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years.

Note 2: *Release Limits for Specific Disposal Systems.* To develop Release Limits for a particular disposal system, the quantities in Table 1 shall be adjusted for the amount of waste included in the disposal system compared to the various units of waste defined in Note 1. For example:

(a) If a particular disposal system contained the high-level wastes from 50,000 MTHM, the Release Limits for that system would be the quantities in Table 1 multiplied by 50 (50,000 MTHM divided by 1,000 MTHM).

(b) If a particular disposal system contained three million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities in Table 1 multiplied by three (three million curies divided by one million curies).

(c) If a particular disposal system contained both the high-level wastes from 50,000 MTHM and 5 million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities in Table 1 multiplied by 55:

$$\frac{50{,}000 \text{ MTHM}}{1{,}000 \text{ MTHM}} + \frac{5{,}000{,}000 \text{ curies TRU}}{1{,}000{,}000 \text{ curies TRU}} = 55$$

Note 3: *Adjustments for Reactor Fuels with Different Burnup.* For disposal systems containing reactor fuels (or the high-level wastes from reactor fuels) exposed to an average burnup of less than 25,000 MWd/MTHM or greater than 40,000 MWd/MTHM, the units of waste defined in (a) and (b) of Note 1 shall be adjusted. The unit shall be multiplied by the ratio of 30,000 MWd/MTHM divided by the fuel's actual average burnup, except that a value of 5,000

MWd/MTHM may be used when the average fuel burnup is below 5,000 MWd/MTHM and a value of 100,000 MWd/MTHM shall be used when the average fuel burnup is above 100,000 MWd/MTHM. This adjusted unit of waste shall then be used in determining the Release Limits for the disposal system.

For example, if a particular disposal system contained only high-level wastes with an average burnup of 3,000 MWd/MTHM, the unit of waste for that disposal system would be:

$$1{,}000 \text{ MTHM} \times \frac{(30{,}000)}{(5{,}000)} = 6{,}000 \text{ MTHM}$$

If that disposal system contained the high-level wastes from 60,000 MTHM (with an average burnup of 3,000 MWd/MTHM), then the Release Limits for that system would be the quantities in Table 1 multiplied by ten:

$$\frac{60{,}000 \text{ MTHM}}{6{,}000 \text{ MTHM}} = 10$$

which is the same as:

$$\frac{60{,}000 \text{ MTHM}}{1{,}000 \text{ MTHM}} \times \frac{(5{,}000 \text{ MWd/MTHM})}{(30{,}000 \text{ MWd/MTHM})} = 10$$

Note 4: *Treatment of Fractionated High-Level Wastes.* In some cases, a high-level waste stream from reprocessing spent nuclear fuel may have been (or will be) separated into two or more high-level waste components destined for different disposal systems. In such cases, the implementing agency may allocate the Release Limit multiplier (based upon the original MTHM and the average fuel burnup of the high-level waste stream) among the various disposal systems as it chooses, provided that the total Release Limit multiplier used for that waste stream at all of its disposal systems may not exceed the Release Limit multiplier that would be used if the entire waste stream were disposed of in one disposal system.

Note 5: *Treatment of Wastes with Poorly Known Burnups or Original MTHM.* In some cases, the records associated with particular high-level waste streams may not be adequate to accurately determine the original metric tons of heavy metal in the reactor fuel that created the waste, or to determine the average burnup that the fuel was exposed to. If the uncertainties are such that the original amount of heavy metal or the average fuel burnup for particular high-level waste streams cannot be quantified, the units of waste derived from (a) and (b) of Note 1 shall no longer be used. Instead, the units of waste defined in (c) and (d) of Note 1 shall be used for such high-level waste streams. If the uncertainties in such information allow a range of values to be associated with the original amount of heavy metal or the average fuel burnup, then the calculations described in previous Notes will be conducted using the values that result in the smallest Release Limits, except that the Release Limits need not be smaller than those that would be calculated using the units of waste defined in (c) and (d) of Note 1.

Note 6: *Uses of Release Limits to Determine Compliance with 191.13.* Once release limits for a particular disposal system have been determined in accordance with Notes 1 through 5, these release limits shall be used to determine compliance with the requirements of 191.13 as follows. In cases where a mixture of radionuclides is projected to be released to the accessible environment, the limiting values shall be determined as follows: For each radionuclide in the mixture, determine the ratio between the cumulative release quantity projected over 10,000 years and the limit for that radionuclide as determined from Table 1 and Notes 1 through 5. The sum of such ratios for all the radionuclides in the mixture may not exceed one with regard to 191.13(a)(1) and may not exceed ten with regard to 191.13(a)(2).

For example, if radionuclides A, B, and C are projected to be released in amounts Q_a, Q_b, and Q_c, and if the applicable Release Limits are RL_a, RL_b, RL_c, then the cumulative releases over 10,000 years shall be limited so that the following relationship exists:

$$\frac{Q_a}{RL_a} + \frac{Q_b}{RL_b} + \frac{Q_c}{RL_c} < 1$$

Appendix B—Guidance for Implementation of Subpart B

[Note: The supplemental information in this appendix is not an integral part of 40 CFR Part 191. Therefore, the implementing agencies are not bound to follow this guidance. However, it is included because it describes the Agency's assumptions regarding the implementation of Subpart B. This appendix will appear in the Code of Federal Regulations.]

The Agency believes that the implementing agencies must determine compliance with §§ 191.13, 191.15, and 191.16 of Subpart B by evaluating long-term predictions of disposal system performance. Determining compliance with § 191.13 will also involve predicting the likelihood of events and processes that may disturb the disposal system. In making these various predictions, it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgment relevant to the numerical predictions. Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgments as well. Because the procedures for determining compliance with Subpart B have not been formulated and tested yet, this appendix to the rule indicates the Agency's assumptions regarding certain issues that may arise when implementing §§ 191.13, 191.15, and 191.16. Most of this guidance applies to any type of disposal system for the wastes covered by this rule. However, several sections apply only to disposal in mined geologic repositories and would be inappropriate for other types of disposal systems.

Consideration of Total Disposal System. When predicting disposal system performance, the Agency assumes that reasonable projections of the protection expected from all of the engineered and natural barriers of a disposal system will be considered. Portions of the disposal system should not be disregarded, even if projected performance is uncertain, except for portions of the system that make negligible contributions to the overall isolation provided by the disposal system.

Scope of Performance Assessments. Section 191.13 requires the implementing agencies to evaluate compliance through performance assessments as defined in § 191.12(q). The Agency assumes that such performance assessments need not consider categories of events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years. Furthermore, the performance assessments need not evaluate in detail the releases from all events and processes estimated to have a greater likelihood of occurrence. Some of these events and processes may be omitted from the performance assessments if there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changed by such omissions.

Compliance with Section 191.13. The Agency assumes that, whenever practicable, the implementing agency will assemble all of the results of the performance assessments to determine compliance with § 191.13 into a "complementary cumulative distribution function" that indicates the probability of exceeding various levels of cumulative release. When the uncertainties in parameters are considered in a performance assessment, the effects of the uncertainties considered can be incorporated into a single such distribution function for each disposal system considered. The Agency assumes that a disposal system can be considered to be in compliance with § 191.13 if this single distribution function meets the requirements of § 191.13(a).

Compliance with Sections 191.15 and 191.16. When the uncertainties in undisturbed performance of a disposal system are considered, the implementing agencies need not require that a very large percentage of the range of estimated radiation exposures or radionuclide concentrations fall below limits established in §§ 191.15 and 191.16, respectively. The Agency assumes that compliance can be determined based upon "best estimate" predictions (e.g., the mean or the median of the appropriate distribution, whichever is higher).

Institutional Controls. To comply with § 191.14(a), the implementing agency will assume that none of the active institutional controls prevent or reduce radionuclide releases for more than 100 years after disposal. However, the Federal Government is committed to retaining ownership of all disposal sites for spent nuclear fuel and high-level and transuranic radioactive wastes and will establish appropriate markers and records, consistent with § 191.14(c). The Agency assumes that, as long as such passive institutional controls endure and are understood, they: (1) can be effective in deterring systematic or persistent exploitation of these disposal sites; and (2) can reduce the likelihood of inadvertent, intermittent human intrusion to a degree to be determined by the implementing agency. However, the Agency believes that passive institutional controls can never be assumed to eliminate the chance of inadvertent and intermittent human intrusion into these disposal sites.

Consideration of Inadvertent Human Intrusion into Geologic Repositories. The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent human intrusion. Some types of intrusion would have virtually no effect on a repository's containment of waste. On the other hand, it is possible to conceive of intrusions (involving widespread societal loss of knowledge regarding radioactive wastes) that could result in major disruptions that no reasonable repository selection or design precautions could alleviate. The Agency believes that the most productive consideration of inadvertent intrusion concerns those realistic possibilities that may be usefully mitigated by repository design, site selection, or use of passive controls (although passive institutional controls should not be assumed to completely rule out the possibility of intrusion). Therefore, inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies. Furthermore, the implementing agencies can assume that passive institutional controls or the intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities.

Frequency and Severity of Inadvertent Human Intrusion into Geologic Repositories. The implementing agencies should consider the effects of each particular disposal system's site, design, and passive institutional controls in judging the likelihood and consequences of such inadvertent exploratory drilling. However, the Agency assumes that the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years for geologic repositories in proximity to sedimentary rock formations, or more than 3 boreholes per square kilometer per 10,000 years for repositories in other geologic formations. Furthermore, the Agency assumes that the consequences of such inadvertent drilling need not be assumed to be more severe than: (1) Direct release to the land surface of all the ground water in the repository horizon that would promptly flow through the newly created borehole to the surface due to natural lithostatic pressure—or (if pumping would be required to raise water to the surface) release of 200 cubic meters of ground water pumped to the surface if that much water is readily available to be pumped; and (2) creation of a ground water flow path with a permeability typical of a borehole filled by the soil or gravel that would normally settle into an open hole over time—not the permeability of a carefully sealed borehole.

APPENDIX B:
RESPONSE TO REVIEW COMMENTS ON THE 1991 PERFORMANCE ASSESSMENT

APPENDIX B: RESPONSE TO REVIEW COMMENTS ON THE 1991 PERFORMANCE ASSESSMENT

As stated in the *Waste Isolation Pilot Plant Land Withdrawal Act* (Public Law 102-579, 1992), performance assessment (PA) analyses shall be provided every two years "to the State [of New Mexico], the [EPA], the National Academy of Sciences, and the EEG [Environmental Evaluation Group] for their review and comment."

The inclusion of this appendix in the 1992 *Preliminary Performance Assessment* marks the third year that the Sandia National Laboratories' (SNL) PA Department has published the complete text of formal comments received from these groups together with responses indicating how comments will be addressed in future PA iterations (Bertram-Howery et al., 1990; WIPP PA Division, 1991a). In previous years this appendix has included comments from the New Mexico Environment Department (1990, 1991), the EPA Office of Radiation Programs (1990), and the EEG (1990, 1991). Comments have been received in 1992 only from the EEG. These comments pertain to the 1991 preliminary PA, as published in the first four volumes of SAND91-0893 (WIPP PA Division, 1991a,b,c; Helton et al., 1992).

Text of comments from the EEG and responses from the SNL Waste Isolation Pilot Plant (WIPP) PA Department follow. Organization of the responses is based on the organization of the comments. The EEG has provided both general comments in which they discuss important issues in the documents and state the conclusions of their review, and specific, page-by-page comments referenced directly to SAND91-0893. The PA Department has numbered EEG comments and inserted responses directly following each comment. EEG's general observations about important issues and conclusions are contained in comments 1 through 18. Page-by-page comments are numbered 19 through 96. In cases where page-by-page comments address points already covered in the general comments, responses are brief, and refer the reader back to the more detailed discussion.

EEG has also provided comments on the WIPP PA Department's responses to comments published in 1991 on the 1990 preliminary performance assessment. These comments are presented with PA responses following the comments on the 1991 documents, beginning on page B-53. Numbers assigned to these comments reflect the numbering used in Appendix B of the 1991 documentation (WIPP PA Division, 1991a). Readers should consult that volume for the original text of the comments and responses.

Comments on SAND91-0893 from the Environmental Evaluation Group, with Responses from the WIPP Performance Assessment Department

Comments dated July 31, 1992

I. Introduction

The Environmental Evaluation Group (EEG) is impressed by the productivity of the Sandia National Laboratories (SNL) WIPP Performance Assessment Group in the second year of detailed performance assessment for WIPP. The four volumes of SAND91-0893 display a massive effort to continue to synthesize a large amount of work and data in the areas of site characterization; in situ hydrologic and rock mechanics studies underground; waste characterization; conceptual models of natural phenomena; and expected behavior of geologic and engineered barriers. A workable mechanism is developing to document the expected evolution of conditions in the repository after decommissioning. Although much work remains to be done, we share the Sandia scientists' optimism that this continued effort will result in providing the best possible basis to assess WIPP's compliance with the EPA disposal standards for high-level and transuranic nuclear waste repositories (40 CFR 191, Subpart B).

This review is organized in four sections. Following the Introduction, Major Conclusions are provided. Certain important issues are identified for consideration in future P.A. efforts in the third section. This is followed by "page by page" comments. The last section of these review comments consists of the EEG reply to the SNL response to the EEG's comments on the 1990 reports. This arrangement has caused some duplication, but in the interest of clarity, it should be acceptable.

COMMENT 1. EEG review of the 1991 P.A. is not complete. For example, detailed comments are provided only on the first four chapters of volume 1, and volume 4. However, these comments are being provided at this time to enable SNL to utilize our thoughts and concerns as they begin to make decisions on the selection of data, scenarios and models, before the calculations begin for the 1992 iteration.

RESPONSE 1. In order to produce an iteration of WIPP PA by the end of each calendar year, the design of the analyses for that year must be decided by April 1. Comments received after that date cannot, in general, be addressed until the following year's PA. For future PAs, the 1992 ***WIPP Land Withdrawal Act*** states that formal comments from the EEG (as well as EPA, NMED, and NAS) should be received within 120 days of publication of the PA documentation if a formal response is required.

COMMENT 2. We have mixed feelings about the organization of the Sandia reports (4 volumes of SAND91-0893). The organization appears quite logical, but still it requires much effort to gather all the information about a particular scenario analysis or to track all the steps of a calculation. For example, the possibility of direct release of waste to the surface through drill-cuttings is first mentioned in Chapter 4 of Vol. 1. Some of the assumptions and considerations as well as the results are provided in Chapter 7 of Volume 2, but one has to search in volume 3 for the input data used for this analysis, even though the input data used in the cuttings code to characterize the drilling mud, drill string, and waste properties was fixed for all cases. However, the fact that four activity levels in the waste were used for this analysis does not become clear until one studies the sensitivity analysis in Volume 4 (Chapter 4). Similarly, the fact that the gas effects considered in the analyses are limited only to the retardation of brine inflow and the structural effects are not considered is not clearly stated anywhere in the scattered discussion of gas effects. We have no specific suggestions to improve the organization except to recommend that the needs of the reviewer should be kept in mind and information should be presented and cross-referenced (by Chapter, Section, and page) so that related information is easily found. In addition, it may be helpful to provide a much expanded Executive Summary (an entire chapter or perhaps a full volume) in which the assumptions, data, scenarios and procedures are more clearly presented in one place.

RESPONSE 2. In general, the PA Department agrees with the comment. The reports have been reorganized for 1992 to improve the presentation. Efforts have been made to provide better referencing and cross-referencing between volumes, and Volume 1 is briefer and presents a clearer overview of the PA.

II. Major Conclusions

COMMENT 3. The 1991 P.A. calculations lack conservatism in assumptions of scenarios, use of parameters and assignment of probabilities, even compared with the 1990 effort. Examples of non-conservative assumptions include: use of 5 km distance for the Culebra transport rather than the site boundary, use of drilling rate median value of one-half of the maximum in 40 CFR 191, not considering any intrusion for the first 1000 years, not considering a scenario involving contaminated brine flows to the surface, use of unjustified K_d values, assumption of double-porosity flow with matrix diffusion to calculate travel times through the Culebra, undisturbed performance analyses only for the expected case, etc. In this sense, the 1991 P.A. reports are not an improvement over the 1990 effort.

RESPONSE 3. With respect to 40 CFR 191B, the purpose of PA is to provide probabilistic uncertainty analyses of realistic estimates of disposal-system performance. Modeling assumptions in general should not made in the context of "conservative" or "nonconservative" but rather in the context of acceptable approximation of reality.

With respect to interim guidance to the Project from preliminary PAs, uncertainty and sensitivity analyses are most useful if performed on the most realistic modeling system available, rather than on artificially conservative assumptions.

The PA Department recognizes that it is possible to characterize some assumptions as "nonconservative." Other assumptions could be characterized as "conservative." (See, for example, Response 44.) We are responsive to comments about specific assumptions, and will work to increase realism in assumptions.

The specific points are addressed individually.

3.1 "The use of 5 km distance for the Culebra transport rather than the site boundary."

The 1992 PA uses the land-withdrawal boundary, 2.4 km from the waste panels.

3.2 "Use of drilling rate median value of one-half of the maximum in 40 CFR 191.

Expert judgment on the probability of human intrusion and the potential effectiveness of passive markers has been incorporated in the 1992 PA. CCDFs are presented comparing releases calculated using these probabilities with releases calculated using the same approach to determining intrusion probabilities used in 1991.

3.3 "Not considering any intrusion for the first 1000 years."

This assumption in 1991 did affect direct releases through cuttings and cavings. The 1992 PA uses better resolution in time for direct releases. Subsurface releases are not believed to be particularly different for intrusions prior to 1000 yr (radioactive decay continues to occur during transport in the Culebra), and because limited resources require the PA Department to balance the total number of calculations with the need to improve model physics and accuracy, we do not provide further resolution of intrusion times for subsurface transport. We acknowledge that the final compliance assessment should have sufficient resolution to demonstrate that the shape of the summary CCDF is adequately captured.

3.4 "Not considering a scenario involving contaminated brine flows to the surface."

The PA Department has performed single-phase calculations for drilling fluid and Castile brine flow to the surface during drilling, and consequences were not important compared to direct removal of cuttings and cavings. We will repeat these subsidiary simulations using BRAGFLO for both release during drilling and long-term releases through abandoned boreholes. Results will be presented in a later volume of the 1992 PA documentation.

3.5 "Use of unjustified K_d values."

Results of calculations assuming K_d=0 were published in Volume 4 of the 1991 documentation (Helton et al., 1992, Section 5.4). The PA Department will continue to examine performance for both K_d=0 and estimates of K_d based on expert judgment until defensible K_d values are available.

3.6 "Assumption of double-porosity flow with matrix diffusion to calculate travel times through the Culebra."

The PA Department's preferred conceptual model for the disposal system, based on available information, continues to include dual-porosity transport in the Culebra, as wells as non-zero K_ds, waste-generated gas, creep closure (included for the first time in 1992), and variable climate. For comparison purposes, Volume 1 of the 1992 documentation (this volume) also contains results calculated for the preferred model assuming single-porosity, fracture-only transport with K_d=0.

COMMENT 4. We continue to remain unconvinced about zero releases following undisturbed performance scenarios. We believe this is due to a combination of misinterpretation of the 40 CFR 191 definition of undisturbed performance and use of non-conservative values of certain input parameters.

RESPONSE 4. The PA Department believes the interpretation of 40 CFR 191 used in the 1991 (and 1992) PA is correct. Screening of events and processes for § 191.13 has identified no natural events with probabilities greater than 10^{-4} in 10^4 yr that will disrupt the disposal system (WIPP PA Division, 1991a, Chapter 4). Non-disruptive natural processes (e.g., climate change) are included in the base-case scenario for § 191.13. This base-case scenario also describes undisturbed performance, as defined for §191.15 in § 191.12(p).

With regard to "non-conservative values for certain input parameters," the PA Department notes that Appendix B of 40 CFR 191 indicates that "compliance [with § 191.15] can be determined based on "best estimate" predictions" (US EPA, 1985, p. 38088). Probabilistic analyses are used for 40 CFR 191B to examine uncertainty in realistic predictions, not to provide conservative performance estimates. (See Response 3.)

The preliminary analyses of undisturbed performance reported in the 1991 PA (WIPP PA Division, 1991b) used realistic estimates of parameter values, rather than probabilistically sampled values. Sensitivity and uncertainty analyses of undisturbed performance conducted during 1991 (WIPP PA Department, 1992; not published at the time of the EEG review) use sampled values for input parameters and confirm the conclusion of the previous analyses. For undisturbed conditions, brine that has been in contact with waste does not migrate to the accessible environment. (Or even a small fraction of the distance to it: in the analyses reported in WIPP PA Department, 1992, potentially contaminated brine did not leave the DRZ.)

COMMENT 5. With respect to the analysis of human intrusion scenarios, it appears that the releases from direct removal of drill-cuttings to the surface would be much more severe if a more realistic distribution of radionuclide concentrations in the waste planned for WIPP is sampled and the first intrusion is assumed to occur at a realistic time interval before 1000 years.

RESPONSE 5. Releases at the surface from earlier intrusions are examined in 1992: see Response 3.3. Radionuclide content of the waste is based on the IDB (US DOE, 1991). We are unsure what is meant by "a more realistic distribution of radionuclide concentrations"; see Comment 15, where EEG observes that the "four activity levels chosen seem reasonable (and probably slightly conservative)...".

COMMENT 6. The 1991 performance assessment has assumed several parameters and physical and chemical processes which have helped to keep CCDFs within the Standards' Containment Requirement limits, but no clear justification is provided for these very non-conservative choices. Expert judgment has been used in lieu of experimentally determined values.

RESPONSE 6. As does the 1992 PA, the 1991 PA presented performance estimates for the preferred conceptual model based on available information about the disposal system (see Response 3.6). Alternative conceptual models were presented in Volume 4 (Helton et al., 1992). The goal of PA is to provide a realistic estimate of disposal-system performance with an understanding of the uncertainty in that estimate, rather than simply a conservative estimate (see Response 3). We disagree that the modeling choices are unjustified, and we note that the implication in Comment 6 that expert judgment is unavoidably non-conservative is incorrect.

COMMENT 7. Another area of EEG concern with the 1991 P.A. calculation is the apparent discrepancies in the estimates of the WIPP inventory of various radionuclides. Uranium-233 inventory assumption provides perhaps the most glaring example that would dramatically affect the total integrated discharges for various scenarios.

RESPONSE 7. See Comment 13 for an expanded discussion of this point by the EEG. The PA Department also notes difficulties in obtaining consistent estimates of waste that will be generated in the future. PAs will continue to use the inventory given in the IDB (US DOE, 1991).

COMMENT 8. As we did in 1991, we would again like to recommend that the 1992 and subsequent P.A. iterations include simulations of engineered modified waste forms to provide guidance to the DOE planners.

RESPONSE 8. The PA Department will do so if resources for additional sensitivity analyses are available.

COMMENT 9. And, to conclude this listing of EEG's major concerns with the 1991 P.A. effort, statements such as "Summary of CCDFs (mean and median curves) lie an order of magnitude or more below the regulatory limits" (p.

ES-6, etc.), are misleading at this stage of performance assessment. Portions of the modeling system and data base are incomplete, conceptual model uncertainties are not fully included, final scenario probabilities remain to be estimated, and the level of confidence in the results has not been established.

RESPONSE 9. The PA Department believes that it is important (rather than "misleading") to present preliminary results conditional on clearly stated assumptions and caveats. We agree that preliminary results should not be used out of context. The full quote from pages ES-6 and ES-7 of the 1991 Volume 1 was "Informal comparison of these preliminary results with the Containment Requirements indicates that, for the assumed models, parameter values, and scenario probabilities, summary CCDFs (mean and median curves) lie an order of magnitude or more below the regulatory limits."

III. Important Issues

Input Data

COMMENT 10. EEG has not yet thoroughly reviewed Volume 3: Reference Data to check the reasonableness of the range of various parameters proposed by individual SNL investigators and the connection between the ranges proposed and the results of the experiments on which they are based. We have serious concerns, however, about the values used for some of the more sensitive parameters which directly affect the outcome of the performance assessment.

Retardation of various radionuclides during transport through the Culebra aquifer is a case in point. For last year's effort, P.A. has relied on the "expert judgement elicitation" of two Sandia lab employees. The only existing k_d measurements on the Culebra rock were made using powdered samples which EEG criticized and rejected in 1979. However, one of the two experts used those data for his expert judgement in 1991! And even though the numbers suggested by the third expert (also a SNL employee) are between 1 and 3 orders of magnitude more conservative, his assumptions of 1% clay in the matrix of the Culebra dolomite and 100% clay filled fractures has no demonstrated scientific basis. It is interesting to note that the P.A. group disregarded the numbers provided by this third expert, but accepted his recommendation to assume a median value of 50% of fractures filled with clay based on a suggested normal distribution between 10% and 90%. No scientific justification for this distribution has been provided.

RESPONSE 10. PA modeling of transport in the Culebra will be revised appropriately when results are available from ongoing tracer column experiments. Until such time, PA will continue to examine alternative conceptual models in which $K_d=0$. The description of clay linings in fractures and the approach to modeling their impact on transport has been revised for 1992 (See Volumes 2 and 3).

COMMENT 11. The P.A. calculations of scenarios with releases through the Culebra dolomite have also relied on the assumption of double porosity flow with matrix diffusion. While the mechanism of matrix diffusion has been successfully assumed in the interpretation and modeling of hydrologic flow tests data, it has never been demonstrated to exist either experimentally or through modeling. The CCDF plots are highly sensitive to the combined assumptions of (1) the presence of clay in the matrix and in the fractures of the Culebra dolomite, (2) mechanics of double porosity flow with matrix diffusion, and (3) high degree of physical and chemical retardation of radionuclides during such transport. In fact, the sensitivity analyses indicate that without these assumptions, the CCDF curves for the scenarios involving flow through the Culebra would violate the containment standards. It is essential, therefore, that very good experimental and theoretical demonstration of the occurrence of these processes be provided.

RESPONSE 11. The PA Department agrees that experimental and theoretical demonstration of these processes is important. We disagree that "matrix diffusion ... has never been demonstrated." Existing hydropad tests indicate that dual-porosity transport on the scales of the tests is the most realistic conceptual model for fractured portions of the Culebra (Kelley and Pickens, 1986; Saulnier, 1987; Beauheim, 1987a,b, 1989; Jones et al., 1992). Planned hydraulic testing will further examine this question (Beauheim and Davies, 1992).

Undisturbed Performance of Repository/Shaft

COMMENT 12. Chapter 4 in Volume 2 devotes 83 pages to a description of the evaluations that have been performed to date. The calculations have been extensive and have involved 4 computational models (Boast II, Panel, Sutra, and Staff2D). The objectives of the calculations this year (summarized on page 4-81 of Volume 2) are primarily cross verification between models and initial approximations of gas generation effects.

All results indicate that migration of nuclides even a few meters up a shaft are orders of magnitude less than the allowable releases in 40 CFR 191. The assumptions are considered conservative but are not claimed to be bounding. These preliminary findings reinforce earlier conclusions that no non-human intrusion scenarios will result in releases and will thus never be a factor in showing compliance with the Standard.

EEG believes a conclusion that non-human intrusion scenarios will never be a problem and can thus be ignored is still unproven. Our reasons for this are discussed below.

This section is entitled "undisturbed performance." The discussion on page 4-63 of Volume 1 about undisturbed performance is misleading. The definition of undisturbed performance is quoted from the 1985 Standard as not including unlikely natural events. This is the correct definition, but it is to be applied only to the Individual Protection Requirements (191.15) and the Groundwater Protection Requirements (191.16). The Containment Requirements (191.13) apply the same probability limits to natural events as they do to disruptive events such as human intrusion. Therefore, the Performance Assessment needs to consider events with probabilities as low as 0.0001 in 10,000 years when constructing the CCDF.

The evaluation of "undisturbed performance" in the 1991 Preliminary Comparison clearly does not consider low probability conditions. For example, all modeling was done with the assumption that the degree of brine saturation in the wastes was 30% or less. The result was relative permeabilities in the waste that are orders of magnitude less than in the surrounding formation.

The values used for permeability in the anhydrite and halite were those from the median/average of the range used for human intrusion scenarios and sampling was apparently not done from the distribution. Likewise the solubility values used were around the center of the range and orders of magnitude below the 90-percentile levels shown in Table 3.3-11 of Volume 3.

It may turn out that calculations will show that truly bounding (or very low probability) conditions will still result in trivial releases from non-human intrusion events. SNL should, however, perform uncertainty and sensitivity analyses for the undisturbed case. An alternate approach might be to calculate truly bounding scenarios to see if it is possible to dispense with non-human-intrusion scenarios without further refining of calculations. These calculations should include a fully saturated room with solubility, and the formation and shaft permeability values at or near the 1.0 cumulative probability level.

RESPONSE 12. Points raised here are addressed individually.

12.1 "Non-human intrusion scenarios [should not be ignored]."

The PA Department agrees. They are included in the base-case scenario for § 191.13. If analyses of undisturbed performance for § 191.15 and 40 CFR 268.6 show a potential for 10,000-yr releases to the accessible environment, these releases will be included in CCDFs for § 191.13. As noted in the 1992 PA and previous iterations, the WIPP PA Department has high confidence that realistic models will continue to show that human intrusion is the only likely event with the potential to result in any releases to the accessible environment.

12.2 Definition of undisturbed performance.

See Response 4. The PA Department believes its usage is correct.

12.3 "The evaluation of 'undisturbed performance' in the 1991 Preliminary Comparison clearly does not consider low-probability conditions. For example, all modeling was done with the assumption that brine saturation in the wastes was 30% or less."

This comment suggests a misunderstanding of the PA modeling system. Brine saturation in the waste is "assumed" only for initial conditions. At all other times, it is a model-calculated quantity dependent on the material properties used in the model, the initial and boundary conditions, and the fundamental equations used to describe two-phase fluid flow. PA makes no *a priori* assumptions about the probability of model outcomes.

12.4 "The values used for permeability ... were ... median/average."

See Response 4. The comment is correct.

12.5 Implied request for "truly bounding (or very low probability) conditions."

See Responses 3, 4, and 6. The goal of PA for 40 CFR 191B is uncertainty analysis of realistic conditions, not worst-case analysis. The PA Department has completed uncertainty and sensitivity analyses for the undisturbed case (WIPP PA Department, 1992) and will continue to perform them in the future.

Uranium-233 Inventory

COMMENT 13. The 1991 Comparison lists a design inventory for Uranium-233 of 305 Ci (103.7 Ci CH and 201.5 Ci RH). This value is derived from the 1990 IDB (Integrated Data Base) where weight fractions of the major radionuclides of the mixes are reported. The IDB did not report the inventory of each radionuclide. The value in the 1987 IDB was about 7800 Ci.

The only detailed inventory document we are aware of is DOE/WIPP 88-005 ("Radionuclide Source Terms for the Waste Isolation Pilot Plant"). This report was never, to our knowledge, issued as a final report. However, we have been told by Westinghouse personnel that it is the major data base that was used to develop subsequent IDB reports. This document gives the following values:

CURIES OF URANIUM-233

Facility	CH - TRU		RH - TRU		
	stored	NG	stored	NG	
ORNL	2608.0	4459.0	0.0	0.0	
INEL	574.0	1.0	18.9	4.0	
LANL	48.0	0.0	0.0	0.0	
	3230.0	4460.0	18.9	4.0	= 7713 ci TOTAL

Also in 1983, EEG obtained an estimated radionuclide composition for all TRU stored at INEL. The estimate for U-233 was 862 Ci total, with less than one curie of this in RH-TRU.

It has been our experience that it is difficult to "back numbers out" of the IDB. The various tables are summaries of data and are not internally consistent. In order to calculate the curies of a radionuclide one has to assume that the grams per cubic meter of transuranics in each mix are the same. For example, when this assumption is made in Tables 3.5 and 3.8 of the 1990 IDB for ORNL CH-TRU, one calculates 25,400 Ci of alpha radioactivity. Table 3.5 lists 17,500 Ci.

Uranium-233 is one of the more critical radionuclides for performance assessment because of its expected greater solubility and lower retardation coefficient. The importance of uranium radionuclides to the Performance Assessment is indicated in Table B-4 (Volume 2) where 94.5% of the Total Integrated Discharge is attributed to U-234 and 4.3% is attributed to U-233.

The U-234 inventory of 3315 Ci is from the decay of 9.26 million curies of Pu-238. A U-233 inventory 25 times greater than that used in this report would increase the Total Integrated Discharge from 0.065 to 0.13.

SNL needs to carefully review estimates of the inventory for Uranium-233 and other radionuclides. Data should continue to be updated and obtained more directly than from the IDB values.

RESPONSE 13. The PA Department has little to add to this comment, except to note that the effects on regulatory compliance of changes in the radioactive inventory may be somewhat muted because allowable releases are normalized to the total inventory. We recognize the potential for discrepancies in estimates of waste not yet generated. Radionuclide inventories for PA will continue to be based on the IDB, however, unless or until an alternative approach is identified.

Cuttings Removal

COMMENT 14. EEG recommended in 1991 that the highly variable radionuclide concentrations in the waste be considered in evaluating the curies of TRU waste brought to the surface in borehole cuttings. The 1991 comparison responded to this recommendation by dividing the waste into four activity levels. An average activity was obtained from sampling on this activity distribution. This average activity was used in Appendix B, Volume 2 for the 60 vector runs with the 45 sampled parameters (which included drill bit diameter). Since the sampled average values differed very little from the simple average (about +2.2% at 1,000 years and +4.0% at 3,000 years), the end result of using a sampled average value was negligible in the Appendix B Tables. However, the activity levels were factored into the CCDF construction and the results appear reasonable.

The sensitivity analysis for cutting removal (in Chapter 4 of Volume 4) concludes that drill bit diameter is not a very sensitive parameter. We agree and recommend that in the future consideration be given to sampling directly on the four activity levels in the waste and use a constant drill bit diameter of about 0.34 m. Also, the quantity of waste removable under various room and brine conditions needs to be better understood (see page by page comments for Volume 4).

RESPONSE 14. The PA Department agrees that the quantity of waste removed under various room conditions needs to be better understood.

COMMENT 15. The four activity levels chosen seem reasonable (and probably slightly conservative) when compared to the waste inventory curies in Table 3.3-5 (Volume 3) and volumes in Table 3.4-5 (Volume 3). However, it is noted that the level 4 activity at 3,000 years and later could not be attained by containers that met the initial criticality limits (200 FGE for a 208 liter drum) because most of the activity would have to come from Pu-239 or Pu-240.

RESPONSE 15. Note that the CUTTINGS code includes radioactive decay, and that the activity levels are based on activity at the time of emplacement.

COMMENT 16. The statement is made on page 4-7, lines 34-37 of Volume 4 that a single borehole would not result in a normalized release that exceeds 1.0 and that an intrusion at an earlier time might exceed 1.0. It would be more accurate to say that a single borehole at 1,000 years could theoretically reach 1.0 and that earlier intrusions could definitely exceed 1.0. This is because drums loaded to the maximum permitted PE-Ci and FGE levels with (for example) 987 Ci Am-241, and 11.4 Ci Pu-239, and 1.1 Ci Pu-240 would have 1262 Ci brought to the surface (1.06 normalized release) from a .944-m (eroded diameter) borehole. Also, permissible loading levels of Pu-238 (1100 Ci in a 208 liter drum) could result in normalized releases exceeding 1.0 for greater than 210 years. Because of the early time effect of cuttings and brine flows brought to the surface, EEG believes that SNL should sample on time as they did in the 1990 comparison and not make the first intrusion at 1000 years in all 60 vectors.

RESPONSE 16. See Response 3.3. Releases at the surface are evaluated for earlier intrusions. PA has not sampled on time of intrusion in 1992, however, and will not in future analyses. As discussed in Section 3.1.3 of Volume 1 of the 1991 PA documentation, stochastic uncertainty (e.g., time of intrusion) and subjective uncertainty (e.g., uncertainty in values for imprecisely known model parameters) are fundamentally different. Confusing the two types of uncertainty complicates parametric uncertainty analyses.

Gas Effects

COMMENT 17. DOE has maintained since 1988 that data on gas generation from TRU waste is needed to narrow uncertainties in the performance assessment. In fact, almost the entire justification for starting waste emplacement at WIPP has been based on the need for data to assess compliance with 40 CFR 191

Subpart B. Naturally, one would look to the performance assessment analyses to verify these claims. The P.A. reports so far have not supported the DOE assertion that in situ gas generation data is needed to narrow or remove uncertainties in performance assessment. In fact, although it is not clearly mentioned in any of the 1991 P.A. reports, the only effects of gas generation used are those that are beneficial to P.A. (reduces the releases to the environment). This is because the gas effects have been used only to further reduce the assumed rates of brine inflow, which proves to be beneficial to P.A. The structural effects of gas production that could result in opening of fractures and providing new pathways and mechanisms for releases have not been considered in the P.A. calculations so far.

The net result of assuming the "good" effects of gas and not the "bad" ones, yields results which counter the DOE claims of the need for more in situ gas data. What is the point in undertaking the expense of gas generation tests when the gas generation from waste is actually beneficial in demonstrating compliance with 40 CFR 191? Would it not be better to use these resources to obtain experimental data on radionuclide retardation, solubility, and the nature of porous media flow through the Culebra, the parameters that have the maximum impact on P.A.?

Of course, the assumption that the gas generation would retard brine inflow and thus would help in reducing the releases to the environment is simplistic. The conditions in the repository are expected to evolve as a result of complex interplay of brine inflow, salt creep, disturbed rock zone (DRZ) development, physical disintegration and chemical decomposition of the waste, and gas generation. To predict the range of possible future conditions, and various pathways of development of such conditions, would require complex modeling of coupled processes such as that presented by Davies, Brush and Mendenhall in SAND91-2378.

EEG recommends that the 1992 P.A. should include gas generation effects and the results should be used to assess the need to collect more gas generation data in situ "to reduce uncertainties in performance assessment."

RESPONSE 17. See Response 12.3. The PA Department does not "assume" that gas generation retards brine inflow. Rather, the retardation of brine inflow by elevated gas pressures is calculated by a sophisticated computational model based on fundamental principles of physics and available data and conceptual models.

Pressure-dependent fracturing of anhydrite marker beds has not been included in the 1992 PA. It will be included in future PAs when adequate conceptual and computational models are available.

Comments by the EEG about the relative importance of additional information about gas generation effects for assessing regulatory compliance apparently apply only to 40 CFR 191B. The PA Department notes that analyses with regard to 40 CFR 268.6 (WIPP PA Department, 1992) were not complete at the time of the EEG review.

Waste Form Modification

COMMENT 18. The calculations published by the WIPP Engineered Alternatives Task Force (EATF - DOE/WIPP91-007) indicate that waste form modification could improve repository performance by reducing radionuclide releases into the accessible environment by up to four orders of magnitude, depending on the release scenario and the waste form modification. However, the EATF was unable to make specific recommendations for waste treatment, noting that more work needed to be completed by the SNL performance-assessment effort. The 1991 performance assessment calculations by SNL did not include simulations of the engineered alternatives to the waste form, although the need for performing those calculations was acknowledged. EEG recommends that the 1992 and future P.A. iterations should include assumed waste-form modifications to better assess the merits of such modifications in demonstrating compliance with 40 CFR 191.

RESPONSE 18. See Response 8.

IV. Page by Page Comments

Volume 1, Executive Summary

COMMENT 19. Page (ES-3), lines 12,17. The statement that computational scenarios are distinguished by the time and number of intrusions does not reflect the methodology presented in Volume 2 (Chapter 2), in that "time periods" 2000 years in duration and not exact times are utilized. The mid-point of each interval is a mean average intrusion time estimated by assuming equal likehood across it. Also, it should be mentioned that the historical drilling rate at the site is the maximum rate required by the Standard, whereas the 1991 P.A. samples on a uniform distribution between zero and the maximum required rate. More detailed concerns with this section will be addressed in later comments.

RESPONSE 19. See Responses 3.1, 3.3, and 16.

COMMENT 20. Page (ES-4), lines 2-8. Without mentioning the fact that many parameter distributions are based on subjective judgements formulated by expert panels, which are not readily amenable to uncertainty and (to a lesser extent) sensitivity analysis, one is led to believe that all parameters utilized are derived from experimental measurements. The use of subjective judgement for this purpose, or the use of expert panels to derive such distributions, should be mentioned somewhere in the Executive Summary to convey this type of existing uncertainty in the P.A.

RESPONSE 20. The 1992 documentation makes the point more clearly.

COMMENT 21. Page (ES-4-5), lines 42-45;1-2. Simulations of undisturbed performance indicate zero releases to the accessible environment. This result is based on current parameter uncertainties, incomplete utilization and understanding of certain processes such as structural effects of gas generation, climate and subsidence effects, and an apparent misinterpretation of the definition of undisturbed performance in the 1985 Standard. Therefore, the absence of an analysis of the "base" scenario together with its sensitivity to parameters is of some concern to EEG. Without such a summary, it is not possible to judge the relative effectiveness of containment, and to determine which parameters have controlling influence, and whether their distributions are derived from subjective or experimental process. All of this information should be available for review in future iterations of P.A.

RESPONSE 21. See Responses 4 and 12.

COMMENT 22. Page (ES-5), lines 8-10. The upper bound of 30 boreholes/km^2/10,000 years mentioned in the EPA Standard was based on the observed frequency of drilling in the vicinity of the WIPP site. Therefore, what is the justification for the use of a rate constant with the observed frequency at the site to be the upper bound and a lower bound of zero? The drilling rate appears to have increased in recent years. It may increase or decrease in the future. A more conservative distribution should be used for the future P.A. calculations and a justification should be provided for the distribution used.

RESPONSE 22. See Response 3.2. Note that the expert panels did not agree that "a more conservative distribution should be used."

COMMENT 23. Page (ES-5), lines 10-13. The use of five disjoint time intervals of 2000 years is apparently based on the need to keep computer simulation costs to an acceptable value, and not on any scientific analysis of the impact of these specific intervals and size on the overall CCDF formulation. As was mentioned earlier, the choice of a midpoint for these intervals is based on a mean expectation within a given interval, but the presence of more than one event within a given interval is seemingly meaningless if tracking of repository history is to be taken into consideration. If the time(s) of intrusion are truly independent from one another, then sampling of any number of intrusion singlets, doublets, triplets, ..., etc., from a uniform distribution of 10,000 years, coupled with a calculation of probabilities of occurrence for these intrusions using the Poisson distributions derived within the text, would have possibly been more representative and less arbitrary than the methodology used in P.A. for this purpose. Hence, the five time intervals selected by this methodology would have been of unequal length with possible overlaps.

RESPONSE 23. See Responses 3.3 and 16.

COMMENT 24. Page (ES-5), lines 13-15. Geophysical (TDEM) anomalies at the level of the upper Castile Formation underlying the waste panels indicate the presence of a brine reservoir. However, short of extensive drilling down to that horizon, one can never be certain about the presence or absence of a brine reservoir at that depth or the fraction of the area underlain by the waste panels to be occupied by brine. EEG recommends that while credit may be taken for the uncertainties of a future drillhole reaching that depth, it should be assumed that any hole reaching the upper Castile would encounter pressurized brine reservoir with properties similar to the one encountered by the borehole WIPP-12. To attempt to delineate the fraction occupied by brine on the basis of the TDEM contours is not a valid exercise.

RESPONSE 24. The WIPP PA Department agrees that "one can never be certain about the presence or absence of a brine reservoir." Therefore, we have used available information to provide a reasonable estimate of the uncertainty in our knowledge about the absence or presence of a brine reservoir. The purpose of PA is to provide realistic estimates of performance, not worst-case estimates (See Responses 4 and 12).

COMMENT 25. Page (ES-5), lines 15-18. The four activity levels chosen appear to be reasonable, and probably slightly conservative, when compared to the waste inventory curies in Table 3.3-5 (vol. 3) and the volumes of waste in Table 3-4-5 (vol. 3). It should be noted, however, that the level four activity at 3000 years and later could not be attained by containers that met the initial criticality limits (200 FGE for a 208 liter drum), because most of the activity would have to come from Pu-239 or Pu-240.

RESPONSE 25. See Responses 5 and 15.

COMMENT 26. Page (ES-5), lines 28-38. It is not mentioned that the dual-porosity model being employed, and the consequently large retardations ascribed to the fractures and the matrix (both chemical and physical) have not been proven to be representative at the site. EEG voiced concern in the 1990 P.A. over the use of unjustifiably large retardation factors ascribed to the fractures and matrix. The 1991 P.A. which shows even larger maximum retardation factors only exacerbates our concerns that these factors have not been experimentally justified. Finally, we are still concerned over the use of Expert Panels to derive parameter distributions that can be measured experimentally. Any potential impact that such use will have on the C&C agreement between DOE and the State has been ignored. This Summary should reflect these uncertainties.

RESPONSE 26. See Responses 3.5, 3.6, and 10.

COMMENT 27. Page (ES-6), lines 13-27. This section does not state that the cuttings/corings removal scenarios are not completely modeled, which is important because these types of events dominate the CCDF. Furthermore, it appears that these scenarios would result in much higher releases if a more realistic distribution of radionuclide concentrations is sampled and the first intrusion is assumed to occur much sooner than 1000 years. It is important to know the magnitude of the low probability significant releases and the parameter sensitivity for such releases. This should be provided.

RESPONSE 27. See Responses 3.3, 5, and 15. Emphasis on the importance of cuttings and cavings is more carefully noted in the 1992 documentation. Consequences of core drilling have not been analyzed explicitly because this type of drilling is not commonly used in exploratory boreholes that reach the WIPP horizon. Total volume of waste removed by coring, like that removed as cuttings, would probably be most sensitive to the diameter of the drill bit.

COMMENT 28. Page (ES-6,7), lines 24-2. Statements such as, "summary of CCDFs (mean and median curves) lie an order of magnitude or more below the regulatory limits" are misleading at this stage of performance assessment for reasons summarized in lines 37 to 42 of p. ES-6 and in our major conclusions.

RESPONSE 28. The PA Department disagrees. See Response 9.

COMMENT 29. Page (ES-7), lines 10-11. EEG disagrees with the statement that the WIPP project has satisfied the natural resources assurance requirement outlined in 40 CFR 191.14(e). A review of the referenced DOE report (DOE/WIPP 91-029, August 1991) was provided to WPIO on December 27, 1991. The EEG letter made constructive suggestions towards achieving compliance with the requirement. We have not yet received a reply to our letter. Our position is that the determination that this mineral-rich site is acceptable will be made by the results of the P.A. with drilling rates applicable to a mineral-rich site.

RESPONSE 29. With regard to drilling rates, see Response 3.2. The PA Department is not familiar with the status of the DOE's response to the letter mentioned in the comment.

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COMMENT 30. Page (1-13), lines 4-8. The Consultation and Cooperation Agreement requires DOE to consult and cooperate with various branches of the New Mexico State government and with EEG and not just with the N.M. Environment Department. This change from the 1990 report (SAND90-2347, page I-20) is obviously deliberate, but wrong. In fact, the C and C agreement mentions no particular State agency, but does mention EEG.

RESPONSE 30. Text describing the participants in the WIPP Project has been revised in the 1992 documentation to reflect the 1992 Land Withdrawal Act, which clarifies the EEG's role as a reviewer.

COMMENT 31. Page (1-13), lines 8-18. The Environmental Evaluation Group (EEG) is the only full-time independent review group for the WIPP project and has been conducting this work since 1978. The ACNFS is now defunct and the DNFSB has only commented on the clarification of some DOE Orders' applicability to WIPP. This paragraph and the Synopsis (page 1-32) should appropriately describe the role of the review groups, and list them in the order of their importance and involvement with the WIPP project.

RESPONSE 31. See Response 30.

COMMENT 32. Page (1-15), lines 5-9. The well that bottoms within the WIPP site (James Ranch Unit No. 13) is not only "capable of producing gas," but has been producing gas and condensate since January 1983, except for a shut-in period of one month in July 1985 and for three extended periods of several months beginning in April 1987. This well has produced over 3 million MCF of gas to date.

RESPONSE 32. The text has been revised, and now cites the report by the EEG documenting production from this well.

COMMENT 33. Page (1-25), lines 43-5. What is "an extensive experimental area ... under construction north of the waste disposal area"?

RESPONSE 33. This refers to the underground experimental area excavated north of the waste-disposal area.

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COMMENT 34. Page (2-4), lines 18-21. This agreement has already been broken by allowing resource extraction from the WIPP site through slant drilling. What are the plans to correct the situation?

RESPONSE 34. The question should be addressed directly to the DOE.

COMMENT 35. Page (2-7) lines 32-44. EEG does not consider it appropriate to use expert panel judgement on parameter distributions, which can be determined experimentally as was indicated in the review of the 1990 P.A. This is particularly true for parameters which have great impact on the resulting CCDFs, such as radionuclide solubility and chemical retardation. The P.A. has not addressed the conflict between using retardation values derived in this manner and the current C & C agreement between DOE and the State. Furthermore, EEG questions whether the current use of expert panels and "expert judgement" by SNL goes beyond the intent of the Standard. Clearly, this is an unresolved policy issue.

RESPONSE 35. Parameter values for solubility and retardation are being examined experimentally. Expert judgment is used for these parameters in the 1992 PA to provide interim guidance to the Project until experimental data are available. We note that the evidence that these parameters "have great impact on the resulting CCDFs" comes from analyses using expert judgment. Without the guidance provided by expert judgment, conclusions about relative importance of these parameters would be unsupported.

Although the PA Department agrees with the EEG about the importance of experimental data for all important parameters, and particularly for solubilities and retardations, we question the usefulness of a philosophy that demands in an absolute sense that all distributions which can be determined experimentally must be so determined. First, it should be noted that relatively few parameters in a natural system can be known completely from experimentation. Second, the philosophy presupposes that all parameters are of equal importance and that there are unlimited resources and time for experimentation. One of the purposes of iterative PA is to identify important parameters so that resources may be allotted sensibly. The EEG acknowledges this purpose: see, for example, Comment 17.

Volume 1, Chapter 3 - Performance Assessment Overview

COMMENT 36. Page (3-8), lines 26-30. If the statement is true that most parameter distributions will be of the subjective type as opposed to distributions obtained by classical statistical techniques, then the resulting CCDFs obtained from such an analysis will be mostly subjective as well. While it is possible to perform uncertainty analysis of a subjectively derived CCDF, the meaning of such an exercise is questionable from a quantitative point of view. Also, the statement of the possibility that some distributions will be obtained experimentally is contrary to what is expected for assessing WIPP in a quantitative sense to the greatest degree possible. Does the Standard allow such a procedure for highly sensitive parameters for which it is possible to obtain experimental data to perform statistical analysis? EEG has already noted problems of this type in the 1990 P.A. comparison to the Standard, along with attendant problems in devising uncertainty analyses with this approach. The current P.A. comparison increases this concern because it appears to be adding more uncertainty (subjective) to the results by design than it is explaining.

RESPONSE 36. See Response 35. Few, if any, parameters in a complex, spatially varying natural system can ever be known well enough from experiments or field observations to provide a meaningful basis for pure classical statistical analysis. Informed, subjective judgment of analysts invariably enters into the interpretation of data at many stages, from field and laboratory measurement to the construction of distributions for model parameters. Because data often cannot be collected specifically for the parameters used in models, and can only rarely be collected at the scale at which they are used in models, subjective judgment fills an important and valuable role in performance assessment. The PA Department acknowledges the preeminent importance of experimental data, but does not wish to obscure the role of subjective judgment in PA.

COMMENT 37. Page (3-16), lines 21-38. The explanation of Type A and Type B uncertainty for stochastic and subjective variations, respectively, seemingly attempts to legitimize the use of subjective uncertainty over uncertainty derived from classical statistical measurements of experimental data. Also, subjectivity is extended to represent stochastic uncertainty as well. In fact the CCDFs presented in the current P.A. use subjective distributions to construct both ordinate and abscissa. Furthermore, these CCDFs have been derived through the use of Latin Hypercube Sampling of the subjective distribution(s) for both axes. An important question arises as to what is being measured in uncertainty analysis when the CCDFs have been constructed from such a large number of subjectively derived distributions. Is there such a thing as a "subjective" mean or median? Are some subjective distributions more "real" than others? Do they all receive equal "weighting," including the "few" that have been derived from experimental measurements at the site? EEG questioned the meaning of such analyses when experimentally derived distributions were "mixed" with those of subjective origin in the 1990 P.A. The reply (and one which is reflected in the current P.A.) is that very few of the distributions were of the experimental type. How then do site-specific measurements and observations enter into the P.A. process? If site-specific information is important and is being (or will be in the future) utilized, then this report should give a clear and concise statement as to how this type of information is being (or will be) used to formulate the subjectively derived distributions, and experimental measurements should be displayed on the distributions being utilized. A plot of distributions without real data-points such as are presented in Volume 3 are not very supportive. EEG realizes that some parameter distributions are not amenable to experimental derivation, but for those which can be measured on a site-specific basis, every attempt should be made to determine parameter distributions by this approach.

RESPONSE 37. See Responses 35 and 36. See also the discussion of cdf construction in Chapter 1 of Volume 3 of the 1992 documentation.

COMMENT 38. Page (3-17), lines 38-43. The term, nR, is defined as the "normalized release" for TRU waste. It should more appropriately be defined as the "normalized fractional release" for CCDF construction purposes.

RESPONSE 38.

The PA Department will continue its usage, which we believe to be correct and unambiguous.

COMMENT 39. Page (3-35), lines 22-28. What is the basis for the assumption that the TS scenario has no impact on releases from the repository? There is no information in the current or previous P.A. indicating that this is the case, and it was not excluded in earlier screening efforts to be of no great consequence. In a response to an EEG concern in the 1990 P.A., it was stated that a modeling strategy had not been developed. Is this still the case in 1991? If this is the case, then how was the assumption about TS events made? If the modeling strategy is now complete, then what are the test results to justify the assumption on TS events in 1991? Also, there is no mention of climatic change as part of the scenario characterizations, although this parameter is mentioned at other locations in the current P.A. reports.

RESPONSE 39. The statement in question about the TS event was misleading. PA will examine the effects of subsidence related to potash mining when conceptual and computational models are available. Climatic change is included in the base-case scenario.

COMMENT 40. Page (3-35), lines 30-45. Computational scenario probabilities and consequences for the 1991 P.A. are based on:

1) number of drilling intrusions
2) time of drilling intrusions
3) whether or not a single panel is penetrated by two or more boreholes, of which at least one penetrates a brine pocket and at least one does not
4) the activity level of waste penetrated by the boreholes.

The third condition presumably refers to an E1E2-type scenario, where any number of penetrations could intercept both a waste panel alone or both a waste panel and an underlying brine pocket. It excludes the following:

a) whether or not a single panel is penetrated by two or more boreholes, none of which intercept a brine pocket
b) whether or not a single panel is penetrated by two or more boreholes, all of which intercept a brine pocket
c) whether or not a single panel is penetrated by one borehole which intercepts a brine pocket (E1).

Cases (a) and (c) differ primarily in the amount of cuttings released to the surface (assuming an intact plug above the Rustler Formation). Cases (b) and (c) differ primarily in the amount of cuttings released to the surface by drilling and by shearing of material from the borehole by the extruding brine (assuming an intact plug within the Salado Formation). It is not clear whether case (3) above takes into account the extra cuttings from multiple intrusions or takes into consideration single-intrusion events in its definition of computational scenarios. Does case (3) apply only to groundwater transport in the Culebra Dolomite? If not, how are the above exclusions (a,b,c) justified in the definition of computational scenarios?

RESPONSE 40. The text apparently should have been clearer. The calculations did address all of the points raised, and did not exclude the listed cases. Multiple intrusions were allowed, and cuttings were calculated for each.

COMMENT 41. Page (3-36), lines 1-52. In the selection of discrete time intervals, why must they be:

a. of equal duration (this P.A. uses 2000-year intervals)
b. disjoint (100-2000, 2000-4000, 4000-6000, 6000-8000, 8000-10000)
c. only 5 intervals?

What are the implications of these conditions on the construction of the CCDFs for P.A., as opposed to more stochastic variation of (a), and the use of more intervals(c), which may or may not be disjointed? Would it not have been more consistent to have selected a given year at random from each interval using LHS, since in effect the division of the "even" distribution of year numbers from 1 to 10000 was partitioned into equal probability areas by this approach: instead of assuming that intrusions occurred at 1000, 3000, 5000, 7000, and 9000 years, say at 656, 3200, 4800, 7800, and 9100 could have been selected at random from within each interval of the distribution. Hence, the time intervals utilized in Eq. 3-23 would not necessarily be equal, and would reflect the LHS methodology utilized for other parameters. The latter would still conserve disjoint (but possibly unequal) intervals. Another approach would have been to sample single, doublet, triplet,... years of intrusion from the even distribution of years between 1 to 10000 years (possibly excluding any intrusion occurrences below 100 years), and calculating intrusion probabilities using Eq. 3-27. This would result in possible disjoint and unequal time intervals. Such an approach would minimize any bias that repository history would have on the resulting CCDFs. Why were these (or other) approaches not considered? Finally, it is not clear that in the definition of n(1), n(2), n(3)... that these values are not necessarily equal to 1, 2, 3,.., respectively. An analysis of Eq. 3-27 indicates that they do not have to equal these values when calculating the values in Table 3-2 using Eq. 3-27. The definition needs to be clarified in this respect.

RESPONSE 41. See Response 3.3. The 1992 PA provides better resolution for surface releases from early intrusions. Subsurface releases are believed to be less sensitive to the time of intrusion because decay continues to occur during groundwater transport. The five time intervals were selected for computational efficiency.

COMMENT 42. Page (3-37), lines 1-5. What is the basis for the statement that subsidence events and single borehole penetrations into pressurized brine pockets "do not appear to be important" in the determination of scenario consequences, and therefore are not considered in the 1991 P.A.? One of EEG's concerns for the 1990 P.A. was the exclusion of subsidence events (TS) from consideration. One of the replies to this concern was that such an event was not yet modeled. Was it modeled for inclusion in the 1991 P.A., but not considered? If so, where is the documentation that such an event may not be important in P.A. If the modeling of this event is not complete, then how can such a statement be supported? Also, why was it not originally screened out as being of little consequence at an earlier stage of P.A.? It is still part of the event tree in Figure 3-14. Also, why is the E1 event not considered important in lieu of the release of cuttings and eroded materials to the surface? Is the E2 scenario also not important on this basis? Does the scenario have to be of the form described by Eq. 3-23 (E1E2 related) to be important enough for consideration?

RESPONSE 42. See Response 39 with regard to TS. Surface releases from E1 and E2 were included in the 1991 and 1992 PA and will continue to be included. Note that, as modeled, the quantity of cuttings/cavings released from the two types of intrusions is the same, and that the total release of cuttings and cavings dominates the summary CCDFs for the preferred conceptual model.

COMMENT 43. Page (3-38), lines 1-31. Equation 3-28 is a versatile equation for estimating the probability of any combination of intrusions within designated time intervals, including multiple intrusions in combination with a variety of intrusions in other intervals. Since n(i) can take on any value including zero (although not clearly explained in the text) in any of the intervals, all of the intrusion combinations in Table 3-2 can be obtained with this single equation. However, Eq. 3-29, which expresses the probability of the specified intrusions having penetrated specific activity levels of waste, needs more explanation or at least an example of its use to make it clearer. For instance, suppose there are two activity levels of waste, each with a probability of 0.5, and two boreholes are specified; one in time interval 2 and one in time interval 3. Then the probability of occurrence using Eq. 3-28 equals 0.01673 as shown in Table 3-2. Secondly, assume that one wants to know the probability of both boreholes hitting activity level 2, then the product series in Eq. 3-29 will predict 0.25 correctly. The same would be true for both boreholes striking activity level 1. However, some confusion arises when this equation is used to predict the boreholes striking activity level 1 and 2 since there are two ways to arrive at this possibility. Equation 3-29 gives the correct probability because Eq. 3-28 accounts for the number of permutations: any value in Table 3-2 can be computed as the product of the number of permutations of the intrusion combination times the probability of the intrusions occurring in the same time interval. Thus, the probability of three intrusions in time intervals 2, 3, and 4 (1.098E-02, Table 3-2) can be calculated as the product of the probability of three intrusions in a single time interval (such as for 2, 2, 2;3, 3, 3;4, 4, 4) times the number of permutations of 2, 3, and 4 time intervals (6): 6 x 1.829E-03 = 1.098E-02.. etc. In fact, Eq. 3-28 is not required in its product form (II) to obtain the values in Table 3-2 if the permutations of the intrusion combinations are utilized in this manner and the time intervals are equal:

$$p(n)= cf*j!*(\lambda^{n}*\Delta t^{n}/n!)*(\exp(-\lambda*(b-a))$$, where

n	=	number of intrusions
j	=	permutation number (j less than or equal to n)
Δt	=	time interval (less than or equal to (b-a)
b	=	time at end of total time interval
a	=	time at beginning of total time interval.
cf	=	correction factor for presence of first time interval in permutation number.. (1, 2), (1, 1, 3).. etc., (cf=1.0 if all time intervals are equal, see below).

The correction factor (cf) for the first time interval (1900 years) as opposed to 2000 years for all other time intervals (2, 3, 4, 5) depends on how many times it appears in the permutation:

$$cf = (1900/2000)^a, \text{ where}$$

a = number of times interval 1 appears in permutation number.. a=1 for (1, 2); a=2 for (1, 1, 2); a=3 for (1, 1, 1, 4); a=0 for (2, 3, 4); a=2 for (1, 1, 2, 4)..etc.

This equation can be extended to include other unequal intervals as well.

RESPONSE 43. The author of this comment has noted correctly that probability computations with Equation 3-28 (which applies to a constant drilling intensity λ) can be considerably simplified, particularly for the case of equal time intervals, if the number of permutations of distinct time intervals is taken into account. The PA Department has not determined whether similar simplifications are possible when the drilling intensity is a function of time, $\lambda(t)$, as occurs in the 1992 PA calculations (see Section 5.1 of the 1992 Volume 2). In any case, Equations 3-28 and 3-29 were derived (in Sections 2.4 and 3.2, respectively, of the 1991 Volume 2) in a way that guarantees applicability to situations where the drilling intensity is any bounded, integrable function of time on the interval (0, 10,000 years). Because constant λ is such a function, Equations 3-28 and 3-29 are correct, although possibly computationally inefficient.

COMMENT 44. Page (3-45), lines 22-37. It is not clear how rCi releases are incorporated into CCDF construction if it is assumed that there are five different activity levels for TRU wastes in the 1991 P.A.? Does this statement mean that they could be used if only one activity level (such as the mean) were used? More explanation is needed. Also, please explain the basis for the assumption that an E1E2 scenario can only take place when the necessary boreholes occur within the same time interval (2000-year duration, as opposed to over a 10000-year duration)? The result of this assumption is to lower the probability of such an occurrence as illustrated in Table 3-1, because multiple intrusions involving different time intervals have higher occurrence probabilities (greater than 2000 years between occurrences). In lieu of the fact that two or more intrusions (one of which penetrates pressurized brine, and one does not) can occur over the entire 10000-year period with higher probabilities (1, 1, 1, 1 has a lower probability of occurrence than 1, 2, 3, 4 for 4 intrusions, see Table 3-2), why are they excluded? Furthermore, how is the time interval between intrusions defined under this assumption? Does not the repository history have any bearing on the ultimate releases, or is this history assumed to be constant for the 1991 P.A.? The third assumption that an E1E2 scenario involving more than two boreholes will have the same release as one involving only two is clearly incorrect if cutting releases are to be incorporated into the scenarios. This assumption would lead one to believe that all cutting releases for multiple intrusions are not being considered in this P.A. Is this true? Why?

RESPONSE 44. More explanation is provided in Volume 4 of the 1991 documentation on the use of varying activity levels to determine releases of cuttings/cavings (Helton et al., 1992). The decision to calculate possible effects of flow between boreholes within a single panel only for those holes that occur within the same 2000-yr period is a simplification made for computational efficiency. Note, however, that the E1E2 flow pattern will persist only as long as a plug between the repository and the Culebra remains intact in one of the boreholes. Although the PA Department assumes other plugs will degrade within a short time, this plug (and others used to maximize brine flow into the Culebra in the E1, E2, and E1E2 scenarios) is assumed to remain intact for the balance of the 10,000 yr. The EEG is correct in observing that some assumptions used to construct the E1E2 scenario are simplistic. With regard to the final question, cuttings/cavings releases from multiple intrusions were included in the 1991 (and 1992) PAs.

COMMENT 45. Page (3-46), lines 49-54. This a very confusing statement in that type B uncertainty (scenario consequences) does not have to be subjective: the more quantitatively meaningful uncertainty in this case would be statistically derived. In fact subjective uncertainty should be the last resort, and parameters should be based on "site-specific" data if at all possible. This statement appears as an attempt to legitimize the use of subjective uncertainty for P.A. as a substitute (rather than as an alternative) for experimentally derived distributions. EEG has expressed concern over the use of subjective parameter distributions for the 1990 P.A. and reiterates that same concern for the 1991 P.A. The same argument can be applied to stochastic (scenario probabilities) uncertainty; however, it must be admitted that some of these characterizations are not amenable to the experimental method and must remain subjective.

RESPONSE 45. See Responses 35 and 36.

COMMENT 46. Page (3-47), lines 30-37. The differential analysis techniques review is very clear as to what methodologies will be used to perform both sensitivity and uncertainty analysis. However, the methods employed are most informative and precise when:

1. All of the parameters used in CCDF construction are sampled from known statistically derived distributions.

2. The LHS sampling technique samples the necessary parameters in a way that the variables in the set (v1, v2, v3,..., n) are a representative n-tuple set of the actual sample space.

3. Variable covariance effects on sensitivity and uncertainty effects are not significant.

Whereas the problems that may be associated with covariance among the parameters sampled by LHS was mentioned in the 1990 P.A., there is no mention of any attempts to determine where (and if) such relationships exist in either the 1990 or 1991 P.A. documents. Also, the effect of subjective judgement on any "actual" covariance among parameters has not been addressed. Are there any field measurements being employed to test for this property at least among some of the important parameters being employed in P.A.? Is it possible to measure covariance from a set of subjectively derived parameter distributions?

It is unclear how the LHS methodology being employed takes into account (or will) possible covariances among some of the parameters. At present 60 samples are obtained from 45 parameter distributions; however, the sequence (from which of the 60 subdivisions of equal probability) of each parameter is not presented in the text. For instance, in the first sampling of the 45 parameters, do all of them come from the first equal probability segment of each distribution 1, 1, 1, 1, 1,..etc., or is each parameter possibly sampled from a random set of probability intervals.. 1, 3, 56, 22, 44,..etc.? If the sampling is taken from different equal probability intervals, then that sequence should be recorded for review, particularly if covariance effects are expected between some of the parameters. Is there a specific methodology for sampling to obtain non-biased samples from such a large number of parameters with (and without) covariance among some of the parameters?

RESPONSE 46. In general, correlations are not included in the PA LHS sampling because available information is insufficient to define meaningful correlations. Some parameters are correlated, and others will be in future PAs as new data become available. For uncorrelated parameters, samples are selected from uncorrelated intervals of equal probability. These sequences are recorded for review in Appendices included in the 1990, 1991, and 1992 PA documentation. For additional information on the methodology for obtaining unbiased samples from a large number of parameters, the reviewer is referred to Section 3.5 of Volume 1 of the 1991 PA documentation (WIPP PA Division, 1991a) and to the references cited therein.

COMMENT 47. Page (3-54), lines 20-45. EEG agrees with the statement on using crude characterization of ranges and distributions as input for P.A. if the analysis is primarily of an "exploratory" nature. However, this message is not conveyed in the Executive Summary, which states that "reasonable confidence" exists in meeting the Standard. In fact a direct contradiction exists with the statement "..care should be taken to avoid assigning unreasonably large ranges to variables" with what has actually taken place with respect to retardation factors and radionuclide solubilities in the 1991 P.A., even when compared to the 1990 P.A. EEG in its comments on the 1990 P.A. addressed the issue of CCDF output and associated sensitivity results as being highly dependent on the ranges assigned to input variables as is discussed in this section and is in agreement. However, this philosophy is not clearly evident in this P.A. What is the reason for this discrepancy? If the 1991 P.A. is still of an exploratory nature, then it should be stated as such, and conclusions drawn from it should be stated in this manner.

EEG also agrees that "often, most of the variation in an output variable will be caused by a relatively small subset of the input variables" as the basis for using rather crude range and distribution assumptions for the parameters to find the most sensitive parameters upon which to direct more resources in characterization. However, this approach may be questionable if some of these ranges and distributions have been grossly overestimated or improperly characterized. In fact "expert panels" were convened to address both solubility and retardation characterizations in 1991 with very little experimental research to justify their use.

RESPONSE 47. See Response 6, 35, and 36.

COMMENT 48. Page (3-57), lines 11-45. It appears that the under-pinnings of P.A. are being discussed in this section. Variables for which experimental designs can be constructed to determine parameter distributions by formal statistical procedures are stated to be in the minority. According to this analysis the majority of parameters are not amenable to this type of formulation for seven reasons. What is the impact of this conclusion on the interpretation of the resultant CCDFs from the viewpoint of the Standard? Does the Standard allow such lack of statistical formalism to practically all of the parameters employed in this exercise? Does it imply that "expert panel" judgement can be used to substitute for "site-specific" data for important "quantitative" parameters? Has this approach been legitimized by EPA? Of the seven reasons stated for proceeding with this approach, only the last two (6, 7) appear to be totally justified: rare geological events are not amenable to experiment, and predicting future human behavior (including human intrusion) over 10000 years is of a speculative nature. The first reason (time-scale problem) is peculiar to long-term trends such as future climatic patterns, geochemical equilibrium, etc., but, in addition, it represents the predictive or extrapolative nature of the Standard as a whole from known properties and processes. Physical and chemical properties of the repository which have controlling influence on repository behavior are mostly time-invariant, and are amenable to statistical formalism. Stated reasons (3-5) are not, strictly speaking, "reasons," but "problems" which must be overcome by experimental design. Problems of scale and heterogeneity can be resolved to an acceptable level of resolution without resorting to subjective judgement, which insures that the level of uncertainty has its roots exclusively in site-specific measurements. In some cases, the concerns for repository integrity due to extra boreholes could be avoided by examining adjacent or upstream locations that have properties similar to the withdrawal area.

RESPONSE 48. See Responses 35 and 36. The PA Department disagrees with the argument presented here. For example, we do not believe that "problems of scale and heterogeneity can be resolved to an acceptable level without resorting to subjective judgment." Note that the suggested extrapolation of data from "adjacent or upstream locations" requires subjective judgment.

COMMENT 49. Page (3-60), lines 17-20. Has the approach of avoiding the use of established distributions (e.g., normal, lognormal, beta) in P.A. been utilized in 1991 (Table 6.0-1, 2, 3, Volume 3 of this P.A.)? If true, then this is a significant departure from the 1990 P.A. Why was this philosophy not followed previously, and what advantage is there to such avoidance?

RESPONSE 49. Assigning "established distributions" to sparse data can result in the introduction of spurious information in the cdf. See the discussion of the Maximum Entropy Formalism by Tierney (1990).

COMMENT 50. Page (3-61) , Figure 3-17. Under the description of the figure: should the word be "quantiles" rather than "quantities"?

RESPONSE 50. Yes.

COMMENT 51. Page 3-74, Figure 3-22. What do the unit marks on the ordinate represent? Are they necessary?

RESPONSE 51. The marks are included to provide a convenient visual frame of reference for the reader. Neither a scale nor units are stated or implied.

COMMENT 52. Page (3-75), lines 25-40. The use of Eq. 3-53 as stated assumes that each input variable is linear with respect to the dependent variable which may not be the case. A multiple curvilinear or linear-curvilinear model could give a better fit to the data. Secondly, the number of variables (45) will probably exceed the utility of this type of equation when trying to distinguish the contribution of each parameter to the total regression sum of squares. Thirdly, the fit should be tested for significance using F-test criteria before any further elaboration should be attempted. Fourthly, each partial regression coefficient should be tested for significance using the t-test to determine the number of input parameters which significantly affect the regression sum of squares, and a step-wise regression approach utilized to derive the final relationship. After the final multiple regression equation is developed (assuming an acceptable multiple-R which is significant at an acceptable confidence level, and all partial regression coefficients are significantly different from zero at an acceptable confidence level), then the individual regression sum of squares for the remaining parameters can be determined (it is not necessary that the relationship of any or all the remaining input parameters be linear related to the dependent variable; there may also be cross-product effects). However, the rather large injected "subjective" variances for most of the input parameters which have been made (in combination with LHS) may not allow most of the partial regression coefficients to be significantly different from zero at an established confidence level, and the resultant total error sum of squares may be overwhelmingly large in comparison with the total regression sum of squares. Any significant relationships for particularly important input parameters such as chemical retardations may be masked by the rather large variances "subjectively" arrived at by external and internal experts. It will be surprising if more than a handful of the input parameters will significantly correlate with the dependent variable, and even then, interpretation of the results will be confounded by the subjective component. All other developments in the remaining sections of Chapter 3 (which are very concise and well written) pertaining to sensitivity and uncertainty analysis may be compromised by artificially injected variances using the subjective approach.

RESPONSE 52. These topics are discussed in detail in Chapter 3 of Volume 1 of the 1991 documentation (WIPP PA Division, 1991a, Section 3.5.2), in Helton et al. (1991), and in references cited therein. With regard to the ranges used for "particularly important input parameters such as chemical retardations," see Response 35.

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COMMENT 53. Page (4-2), lines 35-39. The statement that base-case scenario leads to zero release from the containment area is "apparently true" is made on the basis of a great deal of uncertainty in both parameter and conceptual model determinations. For instance, the effect of colloidal materials and chelation on radionuclide transport has not been addressed in P.A. to date, nor has the full interaction of gas pressurization on transport down MB139 been fully conceptualized. Statements of this type are misleading and should be avoided in P.A. unless they are fully justified.

RESPONSE 53. See Responses 4 and 9.

COMMENT 54. Page (4-7), lines 2-7. This statement should indicate that while drilling intrusions are based on four conditions, the actual sampling scheme is not a generalized process as might be implied, but is only approximated by a sampling design that contains a significant number of assumptions in the use of a Poisson distribution. The impact of this design on CCDFs, which would be obtained from a more stochastic approach, should be included in this report.

RESPONSE 54. See Response 3.3.

COMMENT 55. Page (4-13), lines 9-13. The statement on how screening decisions using qualitative judgment are made for certain events is true only if they can remain unbiased. While it is a simple thing to do in theory, it can be very difficult to do in practice, and a methodology should be developed to deal with investigator bias in making qualitative judgments. Also, the P.A. should indicate where this type of judgment has been used to separate it from those which are based on sufficiently detailed data bases. In general, EEG is not in favor of using "expert judgement" in place of data that can be obtained by laboratory and field experiments.

RESPONSE 55. The PA Department acknowledges that qualitative judgments should identified as such. A methodology has been developed for dealing with investigator bias in making qualitative judgments, and has been applied by the PA Department with panels on solubility, retardation, and the probability of human intrusion.

COMMENT 56. Page (4-14), lines 35-45. Since the predominant shrub in the immediate WIPP area is mesquite (Prosopis sp.), which is usually an invader species and is very inefficient in water utilization if supply is ample (phreatophyte), it is not clear that this species will prevail in the future. Many areas of New Mexico rangeland have been invaded by mesquite as result of overgrazing and it has been very difficult to eradicate once established. Mesquite has both a shallow diffuse root system and a much deeper taproot which "mines" water at relatively impervious interfaces such as the caliche "hardpan," which keeps it relatively dry. If the rangeland area around the WIPP has been overgrazed to the point that invader species such as mesquite have become dominant, then recovery of that rangeland in the future may eventually eradicate this phreatophyte resulting in greater soil moisture at the hardpan interface (hence, greater infiltration losses to lower strata below the rooting zone). Such recovery could occur during a wet cycle. Are there any studies indicating what the climatic climax species may have been in the past? Has overgrazing been a factor in allowing invasion by mesquite, or has this plant been endemic in the area as an arrested seral stage for a long period of time? Also, has the caliche layer in the WIPP area been breached significantly by removal for road construction, other uses, or by sinkholes and playa lakes? (see Environ. Geol. Water Sci., Vol. 19, No. 1, 21-32, 1992)

RESPONSE 56. See Response 57, Comment 91, and Response 91. The PA Department acknowledges that many unresolved questions remain about the effects of plant communities on infiltration and about the changes in plant communities over long periods of time. (See Grover and Musick, 1990, for an analysis of changes in southern New Mexico plant communities during the last century.) However, the PA Department believes it is possible to capture the effects of variations in recharge by directly varying boundary conditions on the groundwater-flow model. The caliche layer is not present in all of the area in which groundwater flow is modeled. For example, it is absent in Nash Draw. The effects of vertical leakage throughout the model domain (with and without caliche) will be considered in future PAs when a three-dimensional regional groundwater-flow model is available.

COMMENT 57. Page (4-15), lines 33-42. These statements are misleading in that the modeling of climate for P.A. in 1991 is more or less a ploy, rather than actual modeling. None of the basic features of temperature and moisture patterns are being used to model precipitation, infiltration, evapotranspiration and runoff (surface and return flow, etc.). The use of injection wells on the northern WIPP boundary to represent climate is hardly representative of near field effects, particularly those which might be interactive with land subsidence. The limitations of the current climate modeling should be presented clearly and concisely in this section, particularly because the base case scenario was not analyzed in the 1991 P.A.

RESPONSE 57. As the documentation clearly indicates, WIPP PA does not contain direct modeling of climate change, but instead approximates possible effects of climate change by varying boundary conditions on the regional groundwater-flow model (see, for example, p. 5-23, lines 5-21 and p. 5-37, line 35 through p. 5-38, line 34 of Volume 1 of the 1991 documentation [WIPP PA Division, 1991a]). See Comment 91 and Response 91 for additional information.

COMMENT 58. Page (4-21), lines 7-9. This section should also describe the 4.8 magnitude earthquake of 1/2/92.

RESPONSE 58. This event occurred after the document was printed.

As a general response that will be referenced below in response to other comments on the screening of events and processes, the PA Department acknowledges that screening of events and processes must be updated iteratively to reflect concerns of reviewers and new information. This portion of the PA has not been updated for 1992 because of limited resources. The PA Department encourages constructive comments on the screening of events and processes and will respond in future PAs.

COMMENT 59. Page (4-25), lines 22-26. The Snyder and Gard (1982) hypothesis of breccia chimney formation was effectively countered by another conceptual model involving dissolution of the Salado salt (Peter Davies, Ph.D. thesis, pp. 104-108 and Proc. Int. Symp. on Salt, May 24-28, 1983, vol. 1, pp. 331-350, publ. 1985). After drilling of DOE-2, EEG accepted the lack of threat to the WIPP site from deep dissolution within the Salado. The discussion should nevertheless include Davies' hypothesis.

RESPONSE 59. See Response 58. The comment will be addressed when event and process screening is updated.

COMMENT 60. Page (4-26), lines 11-14. Dewey Lake Redbeds hydrology has never been properly studied in spite of repeated suggestions by EEG and other review groups that it should be. Dewey Lake Redbeds do not have "low water content." James Ranch wells are completed in this Formation.

RESPONSE 60. See Response 58. The PA Department is aware of the livestock wells producing from the Dewey Lake Red Beds. Text will be revised when event and process screening is updated.

COMMENT 61. Page (4-26), lines 14-29. Recharge and infiltration of water at and in the vicinity of the WIPP site has never been properly studied in spite of repeated suggestions by EEG and other review groups to do so. Because of the lack of information in this area, EEG cannot accept assertions of low consequence of water infiltration now or in the future. This process should not be eliminated from the P.A. process.

RESPONSE 61. See Responses 56 and 58. Text will be revised when event and process screening is updated.

COMMENT 62. Page (4-26), lines 44-45. The statement, "brine concentration generally becomes greater to the southwest" of the WIPP site, is wrong. The Culebra water at H-7 has 3,200 mg/l TDS. The reason for the Culebra water being much fresher (very low TDS) south and southwest of the WIPP site has never been adequately explained.

RESPONSE 62. The EEG's observations about chemistry of the Culebra water are correct. The text in question, however, refers to water in the contact zone between the Salado and Rustler Formations.

COMMENT 63. Page (4-27), lines 8-11. DOE has not physically investigated the nature of the Mescalero Caliche layer at and in the vicinity of the WIPP site, although the argument of this layer acting as a barrier to water infiltration has often been advanced. A private citizen, Richard Hayes Phillips, dug trenches to the Caliche layer near the WIPP site in 1986. These trenches clearly demonstrated that the caliche layer has many gaps through which water can infiltrate. DOE has photographs and videorecordings of these trenches.

RESPONSE 63. See Response 58. The PA Department is aware of Phillips' work. Text will be revised when event and process screening is updated.

COMMENT 64. Page (4-27), lines 12-13. It is not correct to say that the anhydrite layers in the Rustler Formation tend to be unfractured. WIPP shafts have demonstrated the existence of many open fractures in all the zones of the Rustler Formation. See, for example, Plate 1 (p. 80) in EEG-32.

RESPONSE 64. See Response 58. The PA Department is aware of the referenced work. Text will be revised when event and process screening is updated.

COMMENT 65. Page (4-27), lines 36-40. What is the basis for the statement, "the dissolution that formed Nash Draw was a relatively short-lived process that is not continuing at present"? Every other document on the subject concludes that the process is continuing. One can witness the "solution and fill" process, first described by Lee (USGS Bull. 760-D, 1925) and accepted by George Bachman, at 50 sinkholes in the Nash Draw.

RESPONSE 65. See Response 58. The PA Department is aware of the referenced work. Text will be revised when event and process screening is updated. Note, however, that the text discusses an alternative hypothesis for the cause of the large-scale dissolution that created the Draw, and was not intended to deny ongoing local dissolution.

COMMENT 66. Page (4-28), lines 21-34. The conclusion of this summary, that the Nash Draw type dissolution most likely will not reach the WIPP repository in 10,000 years, is acceptable, but the preceding discussion that leads to this conclusion has many inaccuracies and new hypotheses that have never been discussed in the scientific community or the scientific literature.

RESPONSE 66. See Response 58. Text will be revised when event and process screening is updated.

COMMENT 67. Page (4-33), lines 24-31. Was the panel of experts told that EPA's "30 boreholes/km^2 in 10,000 years" number is based on the drilling frequency in the WIPP site area?

RESPONSE 67. The panel was not provided this information in formal documentation. The PA Department agrees that the EPA's upper bound is comparable to past drilling frequency in the Delaware Basin. The panel was provided extensive information about past drilling in the WIPP vicinity, and was encouraged to come to its own conclusions about the relevance of this information to future drilling frequency. They were informed as to the guidance provided by the Standard, but they were asked not to limit their considerations to regulatory issues. For example, they considered modes of intrusion other than exploratory drilling for natural resources. See Hora et al. (1991) and Guzowski and Gruebel (1991) for additional information.

COMMENT 68. Page (4-38), lines 12-15. Since the total dissolved solids (TDS) in water from the H-2 wells is so close to 10,000 mg/l, it cannot be concluded that the Culebra water at the WIPP site is all greater than 10,000 mg/l.

RESPONSE 68. See Response 58. The text will be revised when event and process screening is updated. Note, however, that no claim is made that all Culebra water at the site has a TDS content greater than 10,000 mg/ℓ. Rather, the argument is made that Culebra water within 5 km of the waste panels is not potable. The PA Department believes this to be a reasonable assertion. Reference in the paragraph in question to the definition in 40 CFR 191B of "significant source of groundwater" is misleading, and will be corrected. See Section 2.3 of Volume 1 of the 1991 documentation (WIPP PA Division, 1991a) for a discussion of "significant source of groundwater."

COMMENT 69. Page (4-40), lines 38-43. The statement regarding appropriation of available water supplies to areas with better soils than present at WIPP is dependent on the current climate and the potential water storage capacity of the region. Incorporation of higher rainfall (and distribution pattern conducive to greater storage capacity) may indeed make it economically possible to convert the area surrounding WIPP toward agricultural pursuits. While it may be possible to exclude irrigation as a process in scenario development for other reasons, the argument presented here is not very convincing. A factor of two increase in precipitation may transform the region into a potential "dry-farming" region requiring irrigation only as a supplement during periods of soil moisture deficits. This argument was presented in the 1990 P.A.

RESPONSE 69. See Response 58. Irrigation will be reexamined when event and process screening is updated.

COMMENT 70. Page (4-42), lines 8-40. These statements ignore the probable doubling of precipitation in the study area and the consequent increase of water storage capacity of the region. The requirement of a sufficiently large source of water (line 32) to replace leakage and evaporation losses may be accounted for by the increased amount of rainfall in the form of increased soil moisture and available surface water for agricultural purposes. Why is it unrealistic to consider the use of the Ogallala aquifer northeast of WIPP for agricultural purposes in the area? There is a potential for recharging the aquifer by either natural or man-made activities. Also, is it not conceivable that "pan-evaporation" could be reduced in the future by the use of chemical surface coating of reservoir surfaces if necessary? Potential and actual evaporation and/or evapotranspiration from soil surfaces and consequent natural biomass density increases also need to be discussed from the viewpoint of increased precipitation projected for the study area. The arguments presented in this section are not very convincing because of the omission of potential precipitation increases.

RESPONSE 70. See Response 58. Text will be revised when event and process screening is updated.

COMMENT 71. Pages (4-48,49) lines 33-43-3. There appear to be good reasons why a local "rapid" removal of salt to excavate the WIPP repository may have a possibly significant effect on the overlying units. Effects of salt removal have occurred over a long period of time, and are both a local and a far-field phenomenon. Self-healing could have occurred to further mitigate the response. The response may be more similar to subsidence that has occurred in the area as a result of potash removal, than to long term events. Why was such a comparison and analysis omitted? However, if one is going to be concerned about subsidence due to WIPP excavations, then that due to solution mining of potash in the McNutt zone above the repository should also be considered even though it is not required by the Standard. The conclusions presented in this section do not do justice to the excellent analysis of "subsidence and cavings" presented in previous statements of this section and use a bad example for comparison.

RESPONSE 71. See Response 58. Text will be revised when event and process screening is updated.

COMMENT 72. Page (4-50), lines 15-16. The WIPP waste is not "low level," and there will be some thermal loading by the RH-TRU waste.

RESPONSE 72. See Response 58. The error is noted and will be corrected when event and process screening is updated.

COMMENT 73. Page (4-51, 52), lines 17-45, 1-3. This section on gas generation should state that the PA so far has not considered the structural effects of gas generation, but has limited the consideration to reducing the amount of brine that will flow into the rooms and drifts. The effect of this limited consideration has generally been beneficial for PA demonstration in that the releases with gas generation are less than without.

RESPONSE 73. See Responses 12.3 and 17 for a discussion of the distinction between modeling assumptions and and model outcomes.

It is correct that the 1991 (and 1992) PA did not include conceptual or computational models for possible pressure-dependent fracturing of anhydrite marker beds. This process will be included in PA when conceptual and computational models are available.

The purpose of the discussion here is to determine whether or not an event or process should be included in the development of scenarios for analysis. As such, the discussion need not and should not include a discussion of modeling capability. The PA Department does not screen events or processes on the basis of modeling capability.

COMMENT 74. Pages (4-54), lines 29-31. In lines (14-16) of this section climatic change is recognized as part of the base-case scenario. In the lines commented on it appears that the effect of increased precipitation and possibly changed precipitation throughout the year are not taken into consideration in arriving at conclusions about irrigation and damming considerations. This has occurred in several other sections of this report. Why? Also, Table 4-2 (Page 4-56) indicates that these processes have been screened out because of low probability of occurrence or low consequence. Yet it appears that inclusion of a wetter period has not been considered in arriving at these conclusions. If climate change has been considered in these deliberations, then it should be documented in this report at all locations where these events or processes are discussed.

RESPONSE 74. See Response 58. The text will be revised when event and process screening is updated.

COMMENT 75. Page (4-58), lines 14-17. What is the basis for the statement that subsidence caused by mine openings and explosions caused by waste degradation have no effect on the performance of the disposal system? If this conclusion(s) has been documented elsewhere, then it should be referenced.

RESPONSE 75. See Response 58. The text will be revised when event and process screening is updated.

COMMENT 76. Page (4-66), lines 1-7. It is stated that gas will flow through the upper portions of the drifts and the anhydrite layers A and B and saturate the shaft seals, thereby inhibiting brine migration up the shaft to the Culebra Dolomite. This conclusion must be based on modeling efforts; however, has the large areal expanse of anhydrite layers A and B been taken into consideration in arriving at this conclusion? What was the extent of horizontal gas transport, and what effect does it have on the saturation rate and time of transit to the shaft seals?

RESPONSE 76. Additional analysis relevant to this comment is provided in WIPP PA Department (1992). As the comment correctly notes, the conclusion is model-based, and is therefore not an essential part of the scenario definition. The text has been revised.

COMMENT 77. Page (4-67), lines 11-14. The statement that no radionuclides are released to the Culebra in 1000 years under undisturbed conditions is based on current P.A. modeling efforts. It should be qualified to reflect these uncertainties, and that it is based on current modeling strategies which are not exhaustive.

RESPONSE 77. See Responses 4 and 12.

COMMENT 78. Pages (4-63-73), lines 17 through line 33 on page-4-73. The discussion of the base-case, E2, E1, and E1E2 scenarios is very well written and comprehensive with respect to the current modeling strategies. However, none of the scenarios indicate a flow down MB139 to the accessible environment. In view of the gas pressurization effects which makes this pathway more important, it should be included in this and future modeling strategies.

RESPONSE 78. This pathway is discussed in the cited pages (p 4-66, lines 10-20, WIPP PA Division, 1991a). Simulations of flow along this pathway are referenced in these lines and described in detail in Volume 2 of the 1991 documentation (WIPP PA Division, 1991c, Section 4.2.3.3, p. 4-46/81). Additional analyses have been performed since this review was completed (WIPP PA Department, 1992).

Volume 4 Comments

This uncertainty and sensitivity analysis is very important to the performance assessment effort because it indicates the relative importance of certain model and parameter value assumptions to the outcome. The results are valuable guidance to laboratory and field studies that need to be performed, to reevaluations of conceptual models, and to calculations that should be performed in subsequent iterations of the Performance Assessment.

EEG has reviewed this volume and page by page comments are included. We also respond to each item under the headings insights, possibilities for additional investigations, and possible improvements to the 1992 performance assessments in Chapter 6.

COMMENT 79. A generic comment is that EEG believes these types of analyses should also be applied to the undisturbed performance of the repository. The analysis in Chapter 4 of Volume 2 considers only best-estimate conceptual model conditions. We believe (see our comments elsewhere) that models involving no gas generation and fully saturated storage rooms also need to be considered.

RESPONSE 79. The PA Department agrees that uncertainty analyses should include undisturbed performance. The first such analyses are now complete (WIPP PA Department, 1992). Simulations of disturbed performance without gas generation were included in the 1991 PA to provide a useful comparison to the single-phase results presented in previous years. The PA Department does not plan, however, to continue simulations without gas generation. No conceptual model has been proposed to suggest that degrading waste will not generate gas. See comment 3 for a discussion of realism in PA. Note that brine saturation in the waste panels is calculated by the two-phase flow model. See Responses 12.3 and 17.

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COMMENT 80. Page (2-15), line 12. The accessible environment is assumed to begin 5 km from the waste panels. The present definition of the accessible environment in 40 CFR 191 is the site boundary, which is less than 3 km from some portions of the waste panels. The four volumes are misleading about using the 5-km distance for the accessible environment. The titles of Tables B-4 and B-5 in Volume 2 refer to the Accessible Environment without qualification. A reviewer is required to search through these 4 inches of reports to find out what has been done. Page 6-53 of Volume 2 implies that computations have been made at 3 km. Why weren't the results at 3 km used in Tables B-4 and B-5 and in the Summary CDF? Are the results at 3 km presented anywhere in the 4 volumes?

This is an important issue. The values are probably somewhat greater at the site boundary.

RESPONSE 80. See Response 3.1. Subsurface releases are calculated at the land withdrawal boundary in the 1992 PA, 2.4 km south of the panels.

COMMENT 81. Page (2-16), lines 21-26. Assumptions (2) [E1E2 holes happen in the same time interval] and (3) [more than 2 holes in E1E2 scenario are the same as 2 holes] are not conservative, and without calculations, it is uncertain whether this non-conservatism is significant.

RESPONSE 81. See Response 3 on the question of realism versus conservatism. See Response 44 for observations on the assumptions used in the E1E2 scenario. Note that more than two holes in an E1E2 scenario are the same as two holes only for subsurface releases. Cuttings from multiple hits are included.

COMMENT 82. Page (2-20). As mentioned under the cuttings topic, we believe the activity levels are reasonable and probably slightly conservative. However, the activity Level 4 values could not be obtained for WIPP wastes after 3,000 years if the initial criticality requirements were met.

RESPONSE 82. See Response 15.

COMMENT 83. Pages (3-8) and (3-9). The six cases chosen represent a wide range of cases that could affect uncertainty, and it is appropriate to examine them as has been done in this report. However, it is noted that two cases which probably are more severe than these six have been excluded. These are: (a) gas generation, single porosity, no retardation; and (b) no gas generation, single porosity, no retardation. We recommend that these two cases be examined in the 1992 comparison.

RESPONSE 83. Case (a) is included in the 1992 PA. Case (b) is not: no conceptual model has been proposed in which degrading waste does not generate gas. See Response 79.

COMMENT 84. Pages (4-1,2). Figure 2.1-2 is incorrectly referred to as 2.1-1 on several occasions in these two pages.

RESPONSE 84. The error has been noted.

COMMENT 85. Page (4-10). The importance of uranium radionuclides in groundwater transport is not surprising to EEG. In EEG-9 (September 1981), we concluded that uranium-233 would be the most important radionuclide from the well water pathway.

RESPONSE 85. Results are preliminary, and may be sensitive to distributions used for solubility and retardation that were based on expert panel judgment.

COMMENT 86. Page (4-11). The caption to Figure 4.4-1 should indicate whether the accessible environment is at the site boundary or at 5 km.

RESPONSE 86. See Response 3.1. The omission has been noted.

COMMENT 87. Page (4-17). The ranges of total brine flow into the Culebra Dolomite shown in Figure 4.4-8 appear reasonable. The extensive testing of the WIPP-12 brine reservoir in 1981 and 1982 led to a prediction that WIPP-12 would produce (through an open borehole) 382,000 m^3 at the repository level, 126,000 m^3 at the Culebra, and 56,000 m^3 at the surface.

RESPONSE 87. Data from WIPP 12 was used to construct the PA brine-reservoir model (see Section 4.3 of Volume 3 of the 1991 documentation, WIPP PA Division, 1991c).

COMMENT 88. Page (4-38), Figure 4.5-9. The CCDF plotted on this figure indicates that the mean of releases into the Culebra exceeds the Standard at that location. This figure illustrates clearly why EEG believes it to be very important that brine-flows to the surface from an E1E2 scenario need to be modeled. The WIPP-12 brine reservoir had pressure and compressibility characteristics that would produce (through an open borehole) a flow at the surface that was about 0.45 of that at the Culebra.

RESPONSE 88. See Response 3.4. Note, however, that brine flowing at the surface from a single borehole (as at WIPP 12) will not have circulated through the waste, and will not have the same radionuclide content estimated

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for the brine entering the Culebra for the E1E2 scenario. The comparison is inappropriate.

COMMENT 89. Page (4-38), Line 22. Is it appropriate to call a release that exceeds the standard at a point as "already a small release"?

RESPONSE 89. No.

COMMENT 90. Page (5-37), lines 2,3. The mean value of the single porosity, no gas CCDF is about 2.5 times the mean value for single porosity with gas. This difference may not be negligible as the curves approach the Standard limit.

RESPONSE 90. See Responses 79 and 83 with regard to the no-gas-generation case.

COMMENT 91. Page (5-56), lines 38-40. Modeling the effects of enhanced recharge, rather than predicting climate change per se, appears to be a reasonable approach. Also, the use of the ground surface at the recharge area as the boundary head (Page 5-57, lines 15-19) is a good way to address bounding conditions.

RESPONSE 91. The PA Department agrees with the comment. See Comments 56 and 57. The 1992 approach is similar to that used in 1991. Future PAs will continue to use variable boundary conditions to approximate effects of enhanced recharge related to climatic change.

COMMENT 92. Page (5-60), lines 20-22 and 29-30. The explanation of why maximum recharge has minimum impact on releases to the accessible environment in 10,000 years for single porosity flow appears plausible for scenarios that occur at 1,000 years. However, isn't it likely there will be greater releases from maximum recharge for scenarios that occur later?

RESPONSE 92. Yes. Simulations were restricted to the first time interval by resource limitations. Note, however, that regardless of climate change releases from late-time intrusions will not exceed those from the 1000-yr intrusion.

COMMENT 93. Page (6-3), lines 8-32. This is a well-written paragraph that clearly points out the importance of solubility and distribution coefficient values for americium, plutonium, and uranium. An important uncertainty that is not addressed in Volume 4 is changes in the number of curies and the radionuclide distribution in the inventory. Such changes could significantly change the number of waste units and drastically change the fraction of the inventory that reaches the accessible environment.

An example of the effect of plausible inventory changes is the following: (1) the Uranium-233 inventory is 7800 Ci (the best estimate prior to your current assumptions); and (2) the quantity of Plutonium-238 coming from the Savannah River Site is reduced by 7 million curies. A drastic reduction in the Plutonium-238 inventory is possible for several reasons: (a) the existing inventory (end of 1990) is only 666,000 alpha curies; (b) there has been consideration of not bringing some of the high-curie Plutonium-238 wastes to WIPP because of shipping problems; and (c) there has been talk of obtaining future Plutonium-238 requirements from Russia or elsewhere. With these inventory changes, the number of waste units drops to 4.87 and the quantity of Uranium-234 produced from Plutonium-238 decay is reduced from 3315 Ci to 809 Ci. However, with the increase in Uranium-233, the integrated discharge for vector 9 in Table B-5 (volume 2) increases from 0.14 to 0.49 at 5 km. The curies of cuttings brought to the surface would remain about the same, and hence their fraction of the integrated discharge would also increase.

The variability in inventory needs to be treated as an important uncertainty that has to be determined as accurately as possible and upgraded constantly throughout the Performance Assessment.

RESPONSE 93. See Response 13. Radionuclide inventories for PA will continue to be based on the IDB unless or until an alternative approach is identified.

COMMENT 94. Page (6-14). We have the following comments on the "insights (that) have emerged from these analyses."

1) The drilling rate constant is certainly very important. The expert review process is one way of trying to better predict the future. However, EEG is not completely comfortable with this approach and is not convinced that this is the appropriate way to interpret EPA Guidance. It appears this approach is an attempt to avoid treating the WIPP site as a mineral rich area with underlying brine reservoirs.

2) EEG agrees that the interplay between Salado permeability and gas generation is very important and supports the research programs that are underway.

3) Elemental solubilities are very important. The laboratory work underway is already yielding useful preliminary work. Both laboratory and drum-size solubility tests need to be pursued vigorously.

4) Distribution coefficients are very important and the best way to obtain defensible numbers is with the planned experiments in the laboratory with Culebra cores. An appropriate sorbing tracer field study may also provide useful confirmatory information and should be conducted.

5) A better determination of whether single or dual-porosity is the appropriate transport model in the Culebra is definitely needed. A field tracer test, such as the one recently proposed by SNL, needs to be pursued.

6) EEG believes that the transmissivity fields study for the Culebra is important and should be continued.

RESPONSE 94. With regard to point 1), see Response 3.2 and 67. With regard to points 2) through 6), the PA Department notes that the recognition of the importance of these studies demonstrates the usefulness of preliminary PAs using available data, realistic models, and subjective judgment. See, for example, Responses 3, 4, 6, 9, 12.5, 35, and 36

COMMENT 95. Pages (6-17). Three possibilities for additional investigations are mentioned. Our views on these investigations follow.

1) The 1991 Preliminary Comparison has concluded that cuttings removal is the major component of the likely release to the accessible environment. Therefore, processes that could affect these releases do need to be considered in more detail. During their original scoping studies in 1987-88, SNL used an assumption that in an unconsolidated room the waste in containers would also be unconsolidated and an intrusion borehole would bring all the contents of an intercepted container to the surface. This seems to be a reasonable assumption for those cases where gas generation has prevented room closure and it should be reevaluated.

2) Borehole permeability is indeed an important parameter that needs to be better understood. EEG has taken the position that the Guidance in 40 CFR 191 ("... with a permeability typical of a borehole filled by soil or gravel that would normally settle into an open hole over time ... not the permeability of a carefully sealed borehole") is reasonable and not conservative since recent experience indicates that in practice many inactive boreholes have not been sealed as required by regulations. Therefore, we believe your evaluations should address the permeability of boreholes being filled over time by soil or gravel, and not engineered seals.

3) EEG's views on the manner of addressing pressurized brine pockets in the Castile Formation are discussed elsewhere in the comments.

RESPONSE 95. The points are addressed individually.

95.1 The PA model for borehole erosion results in a borehole diameter greater than the 0.6-m diameter of a 55-gallon drum (see p. 7-16 of Volume 2 of the 1991 documentation (WIPP PA Division, 1991b)).

95.2 Engineered seals are not assumed in boreholes, except as necessary to maximize brine flow into the Culebra for the E1, E2, and E1E2 scenarios (see Response 44). The PA Department has otherwise implemented EPA guidance on borehole permeability consistently since 1989 (Marietta et al., 1989, p. III-53; Rechard et al., 1990, p. IV-7/8; WIPP PA Division, 1991a, p. 6-10, line 55-56; WIPP PA Division 1991c, Section 4.2). Borehole permeability is assumed to be similar to that reported by Freeze and Cherry (1979, p. 29) for silty sand.

95.3 See Response 24.

COMMENT 96. Page (6-18). Possible improvements to the 1992 Performance Assessment are identified. Our views on these follow.

1) Drilling intrusions at times earlier than 1000 years should definitely be considered, as was done in 1990.

2) More thought should be given to how clusters of high activity containers might be located in repository storage rooms. In 1988, EEG evaluated the effects of drilling into an average stack of drums from SRP and LANL because of the reasonable assumption they would arrive in a TRUPACT trailer load and be stacked together.

(Waste Management '88, pp 355-364; also reprinted in EEG-42, Appendix B). Other schemes could also be developed.

3) E2-type scenarios should be considered separately.

4) Direct release of brine to the surface should definitely be modeled. This scenario is perhaps the most critical, is plausible, and has been urged by EEG for years. Note our statements elsewhere in these comments.

5) We agree that E1E2 probability estimates should be improved. The inclusion of this scenario when the second borehole falls in a later time period should be considered. Also, the assumption that panel seal plugs will be effective enough to preclude an E1E2 scenario from developing from boreholes in adjacent panels should be reevaluated.

RESPONSE 96. Points are addressed individually.

96.1 See Response 3.2

96.2 The method used in the 1991 PA (see Section 2.4 of Volume 4 of the 1991 documentation, Helton et al., 1992) assumes some "clustering" of waste--all waste intercepted by a single borehole is assumed to be of a single activity level. This would be unlikely if waste were randomly distributed in the panels.

96.3 E2 scenarios will be modeled separately from E1 when resources permit. Note the discussion in Volume 2 of the 1991 PA (WIPP PA Division, 1991b, section 5.2.5.1, p. 5-25/27) comparing flows from E1, E2, and E1E2-type intrusions.

96.4 See Responses 3.4, 88.

96.5 See Responses 44 and 81.

V. EEG Reply to SNL Responses to EEG's Comments on 1990 Preliminary Comparison

SNL's responses to EEG's comments on the 1990 Preliminary Comparison (SAND 90 - 2347) are included in Appendix B (pages 5 to 43) of Volume 1 of SAND 91-0893. The following reply addresses only those comments that were not satisfactorily answered in the SNL Response or in SAND 91-0893 or those that are still not being addressed in a satisfactory manner. Also, some of the responses are discussed elsewhere in our comments.

COMMENT 5. The question on the use of the 1987 IDB was answered satisfactorily. However, we emphasize that the inventory needs to be as accurate and detailed as possible and constantly updated.

RESPONSE. See Response 13 above to the comments on the 1991 documentation.

COMMENT 8. The section 2.1.6 in SAND 91-0893 (Modifying the Requirements) adds the sentence: "An impact study was recently initiated for TRU-waste repositories, but findings are not yet available." We are very interested in obtaining details of this study as soon as possible. Is this a study related to the TRU waste unit that is attempting to develop a rationale for justifying less stringent containment requirements for WIPP than for a commercial HLW repository?

RESPONSE. The 1985 version of 40 CFR 191 contains a risk/benefit criterion for high-level waste (HLW) and spent fuel (SF). However, there are no such criteria for TRU-waste disposal, and no safety requirements were established that apply to TRU waste. Several recent studies (Klett, 1991; Numark and Phelps, 1992; Klett and Gruebel, 1992) and presentations by J. K. Channell of the EEG and others in late 1991 and early 1992 at the Electric Power Research Institute conferences on the technical basis for EPA HLW disposal criteria have offered approaches to developing criteria for TRU-waste disposal that are different from those in the current version of 40 CFR 191. None, however, have advanced a definitive method of developing a risk/benefit criterion for TRU waste.

COMMENT 19a. Approximately 8 pages are devoted to answering our question about the existence of a disturbed area in MB-139 horizontally from excavated waste storage rooms. A good argument is made for the position that the drop off in permeability is very rapid at the Far Field/Disturbed Rock Zone Interface. Apparently (from line 14 of page B-19), this boundary is assumed to be no farther than the horizontal limits of the excavation. This far field is then taken to have a permeability of 2.87 E-20 m^2 (Table 1, page B-23). This description is not consistent with material presented elsewhere in SAND 91-0893. For example, data plotted on page 2-59 of Volume 3 shows anhydrite permeabilities of 1.0E-18 m^2 at 7.3 m and about 8E-20 m^2 at 10 m and 12.6 m. Also, the statement on page 5-41 of Volume 1 says that the ultimate extent of the DRZ is unknown. Furthermore, on page 4-46 (line 29) of Volume 2 it is stated that brine in the repository will flow in all directions. One would expect movement in all directions if MB-139 is effectively sealed beneath the panel seals and the brine movement from the repository rooms to the shafts (that was modeled for undisturbed performance) was blocked.

EEG still has a concern that contaminated brine could be present in a disturbed zone of MB-139 that extends several meters horizontally from the excavated rooms. This contaminated brine would be brought to the surface with drilling fluid if intercepted by a borehole. Also, depending on the permeability at the point of intrusion, a greater volume of contaminated MB-139 brine could be involved in an E1 or E1E2 scenario event.

RESPONSE. Additional analyses of brine migration from the undisturbed repository are presented in WIPP PA Department (1992). Uncertainty and sensitivity analyses of undisturbed performance will continue to examine the extent of brine migration into the anhydrite marker beds.

The PA Department notes that although the area in which intrusions may intersect radionuclides increases as contaminated brine migrates laterally, the rate at which radionuclides may flow into the hole will be substantially less away from the excavated area in which the waste was originally emplaced. The probability of intrusion will increase if "near misses" are included. Probability of "direct hits" will be unchanged, however, and consequences of "near misses" will be less than the consequences of direct hits already considered in PA.

COMMENT 19b. Merely specifying permeabilities in an engineering design does not prove they will be achieved over periods of thousands of years. Hopefully, the seal test program will provide "justification" of the claimed permeabilities. We have found considerable discussion of borehole permeability effects in Volume 4, but have not found a discussion of shaft seal requirements.

RESPONSE. Uncertainty and sensitivity analyses of undisturbed performance now provide preliminary guidance on seal permeabilities (WIPP PA Department, 1992). Additional guidance will be provided from future such analyses.

COMMENTS 19c and 19d. The issues of climatic change and vertical recharge into the Culebra are recognized by SNL and are still being investigated. We have no further comment at this time.

RESPONSE. Work continues on regional geohydrology.

COMMENT 19e. The response to our comment about uncertainty in the source term is satisfactory for now. However, sometime between now and your final P.A. report, it will be necessary to calculate CCDFs over the possible range of the radionuclide composition in the inventory.

RESPONSE. See Response 13 above to the comments on the 1991 documentation.

COMMENT 19, Brine Slurry Filled Room. The response to this comment (p. 13-36) gives credit to "EEG and others" for raising this issue. Actually the issue was raised by the SNL Performance Assessment Group in a memo titled "Early P.A. Scoping Calculations..." dated April 7, 1987. EEG was presented these calculations in June, 1987 as a serious matter and a presentation was made by SNL to the NAS WIPP Panel on September 22, 1987 in Idaho. The expression "brine-slurry filled room" was first used in the above-referenced memo and in the presentations.

EEG is not persuaded that the existence of a brine slurry filled room can be ignored. In fact, your statement on page B-37, line 1, says that in "the <u>vast majority of simulations</u>.....there is insufficient brine entering the room to fill the pores...." Since 40 CFR 191 is concerned with low probability events, the cases where this could occur need to be considered. The brine could also come from the Castile brine reservoir intercepted in the E1 Scenario. Since the expected condition of the undisturbed repository (Chapter 4, Volume 2) would appear to result in an unconsolidated waste form, we are pleased to see that you are studying waste removal with both consolidated and unconsolidated wastes.

RESPONSE. See the Responses 4 and 12.3 above to the comments on the 1991 documentation. Brine saturations within the waste panels are not assumed, they are calculated based on available realistic models and parameter distributions. The PA Department does not make *a priori* assumptions about the probability of model outcomes. Present modeling does not indicate that the volume of brine in the panels will be sufficient to create a slurry (WIPP PA Department, 1992). Uncertainty and sensitivity analyses will continue to examine brine saturation within the waste.

COMMENT 19, Radionuclide Quantities in Drill Cuttings. You have not responded to our comments on this issue. However, it is noted that the 1991 comparison uses (in Chapter 2 of Volume 2) an average concentration determined by sampling on four activity levels. We will not comment in detail on this methodology at this time except to note that somewhat different results would probably be obtained if random sampling had been conducted on each vector. Also, the fact that much greater quantities of radionuclides could be brought to the surface during the first few hundred years is obscured by arbitrarily having the first borehole occur at 1,000 years.

RESPONSE. See Response 3.2 above to the comments on the 1991 documentation.

COMMENT 19, Contaminated Brine Flows to the Surface. This issue has been discussed with SNL and others for several years. SNL has not denied that there is a need to model this scenario but have not done so, have not explained the reason for the delay, nor given a schedule for when modeling will be done.

EEG believes this scenario may be the most critical one for the PA and that it should be modeled in the 1992 Preliminary Comparison. We do not understand why its modeling is being delayed.

Our arguments for including this scenario have been included in our 1991 comments on SAND 90-2347 and elsewhere and will not be repeated here. We do have two comments on your response: (1) The effect that the "relatively low permeability waste and backfill" will have on the flow of brine at the surface will be uncertain until it is modeled quantitatively. Also, the permeability of a brine-filled room that was unconsolidated at the time of flooding may not be too low; and (2) the statement is made that "unrestricted artesian flow from a Castile brine pocket would normally not be permitted." EEG has presented the only data we were aware of about drilling practices in the Delaware Basin and these data indicate that varying amounts of flow are invariably allowed. We would appreciate receiving any additional data available.

RESPONSE. See Responses 3.4 and 88 above to the comments on the 1991 documentation.

COMMENT 20. The PA team's plans "to examine the effects of varying recharge directly, with uncertainty in the recharge factor..." appears reasonable. There is no need to get bogged down in modeling specific causes of recharge as long as a conservatively chosen range of value is examined.

RESPONSE. See Comments and Responses 56, 57, and 91 above in the discussion of the 1991 documentation.

COMMENT 22. SNL is addressing the issue of retardation factors experimentally at this time. We will follow work on this very important issue closely. SNL does not need to continue to use expert-judgement-provided numbers for retardation "in order to provide guidance to the data-acquisition work." The sensitivity of this parameter has been established by the PA work performed to-date and the importance of experimentally establishing the ranges of K_d and retardation factors for various radionuclides has been well recognized. What more guidance is needed?

RESPONSE. See Responses 3 and 3.5 above to the comments on the 1991 documentation.

COMMENT 23. We are pleased to see continued work in the geostatistics area.

RESPONSE. Initial results from the geostatistics program are incorporated in the 1992 PA. Work continues in this area.

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